NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SPATIAL KNOWLEDGE ACQUISITION AND TRANSFER FROM VIRTUAL TO NATURAL ENVIRONMENTS FOR DISMOUNTED LAND NAVIGATION

by

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September 1998

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1998	Master's Thesis

4. TITLE AND SUBTITLE
Spatial Knowledge Acquisition and Transfer from Virtual to Natural Environments for Dismounted Land Navigation

5. FUNDING NUMBERS

6. AUTHOR(S)
Goerger, Simon R.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research, Cognitive and Neural Science & Technology Division

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

ABSTRACT *(maximum 200 words)*

Navigation and terrain familiarity are critical for mission success in the military. Virtual environments (VEs) have often been suggested as a useful tool in addressing these issues. This thesis research addresses the utility of VEs to improve spatial knowledge of and navigation performance through natural terrain compared to traditional methods. In this experiment, fifteen subjects were assigned to one of three training conditions. The map group studied the environment using only an orienteering map. The real world group studied the environment using the map and explored the actual terrain. The VE group studied the terrain using both the map and a real-time VE. Measures were taken of both route and configuration knowledge. The results suggest four conclusions. First, training conditions have no statistically significant effect on an individual's ability to obtain and demonstrate spatial knowledge of a natural environment. Second, spatial ability plays a significant role in navigation performance. Third, exposure to the actual terrain or to a virtual representation of the terrain seems to eliminate ambiguities in an individual's mental map by providing dynamic imagery to clarify propositional knowledge gained from maps. However, this factor has not been shown to improve performance by the measures used here. Fourth, a high resolution 1:5,000 orienteering map provides extensive detail and consequently, navigation performance in this experiment is not likely to be indicative of performance using a conventional 1:24,000 map.

14. SUBJECT TERMS
Spatial Knowledge, Virtual Environments, Navigation, Orienteering, Geographic Information Systems, Terrain Visualization, Modeling and Simulation

15. NUMBER OF PAGES
311

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFI- CATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

Approved for public release; distribution is unlimited

SPATIAL KNOWLEDGE ACQUISITION AND TRANSFER FROM VIRTUAL TO NATURAL ENVIRONMENTS FOR DISMOUNTED LAND NAVIGATION

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
September 1998

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ABSTRACT

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ACKNOWLEDGEMENT

The Office of Naval Research, Cognitive and Neural Science & Technology Division sponsors this research. I would like to thank Dr. William Krebs and Dr. Dylan Schmorrow of the Operations Research Department of the Naval Postgraduate School for their invaluable assistance throughout this experiment. A warm thank-you goes out to the Computer Science Department's Technical Staff. Specifically, to John Locke for his model building and texture editing skills and to Jimmy Liberato & Rosalie Johnson for their technical expertise with the Silicon Graphics machines. Their assistance was essential for the development of the model and its interface, without which, this study would not have been possible. A special thanks to my classmates in the Simulations and Graphics Track who spent countless hours working design issues and writing code laying the foundation for the experimental design and virtual environment. I would also like to thank the fifteen participants and five usability study participants who gave up five hours of their time to take part in this study - their patience and cooperation is most appreciated. To my research assistant, Andrew Quinn, I owe a great amount of gratitude for his work with monitoring participants, editing participant videotapes, and reviewing experimental procedures. Special thanks to Sandra Day, "The Dragon Lady", from the Thesis Processor's Office for her efforts to insure this document was properly formatted for publication. To my friend and proofreader, Andrea Muth, I owe an immense debt of gratitude for her diligent efforts and thought provoking questions. Her assistance helped me produce a much more lucid and complete document. And of course a very special thank-you to my advisor, Dr. Rudy Darken, for his mentoring, advice, encouragement, patience, guidance, and support.

I. INTRODUCTION

A. PROBLEM STATEMENT

The purpose of this thesis is to evaluate if training in a real-time high fidelity VE is superior in terms of spatial knowledge acquisition as compared to traditional military navigation or orienteering training methods (Chapter II, Section B.1). The research establishes a benchmark from which future research will continue to define the optimal level of fidelity and exposure times required in a vitual environment (VE) to provide spatial knowledge of a complex natural environment.

B. MOTIVATION

1. Important Applications for Spatial Knowledge Acquisition

Spatial knowledge acquisition is important in a variety of applications and professions. We use our spatial knowledge of an environment to move freely throughout our everyday surroundings. Traditionally, we think of people using spatial knowledge of VEs when playing video games to quickly move through a virtual world. However, more vital applications of spatial knowledge can be seen in many areas. Taxi drivers use their spatial knowledge to transport passengers throughout the city. Fire fighters use spatial knowledge to conceptualize and maneuver through the environment where they are working even though the area is obscured by smoke and flames.

In fact, any task that requires movement over a distance or through a complex environment demands some degree of spatial knowledge. Military personnel rely on their spatial knowledge of the environment to perform their missions. Soldiers use spatial knowledge of the environment to move rapidly and undetected to destroy the enemy. Special operations units utilize their spatial knowledge of an environment to quickly move through complex structures when conducting raids or hostage rescue missions. Other highly trained military units and personnel, such as Rangers or Scouts, use their spatial knowledge of an environment to conduct clandestine reconnaissance of an objective. They also utilize their spatial knowledge to establish ambush sites or secure critical terrain such as an airstrip.

2. Proven Concept

Human acquisition of spatial knowledge has been studied for many years. Thorndyke described a simple model for how humans acquire spatial knowledge (Chapter II, Section A) [THOR 80]. Since then, further research has been conducted in many areas which support Thorndyke's model. In the domain of computer science, it has been shown that individuals can gain spatial knowledge of VEs [GILL 97] [RUDD 98] using a mental model comparable to Thorndyke's. Similar research has indicated that detailed VEs can provide spatial knowledge transfer to real world environments [WITM 95] [BLIS 97] [DARK 98].

3. Research Shortcomings

Gaining spatial knowledge of a VE provides little benefit by itself. However, the transfer of knowledge to the real world does have many potential benefits. Individuals can train to perform hazardous tasks in the relatively safe surroundings of a virtual world prior to having to perform them in the actual setting. There are many questions about VEs that have not been answered in terms of how to facilitate a positive transfer of spatial knowledge to the natural environment.

Computers allow us to view environments in numerous ways that are not physically possible in the real world. Viewpoints can be rapidly changed to provide individuals with alternative vantage points. We can examine the same object or location from any direction, plane, or altitude. We can also move through the environment at any speed we desire or merely teleport to the next location. However, the best combination of these capabilities to maximize spatial knowledge acquisition is still unknown. Studies focused on field of view, display devices, input devices, locomotion devices, and the navigation thought process are needed to find the optimal interface for acquiring and utilizing spatial knowledge.

Much of the previous work has focused on increasing fidelity. However, little research has been conducted indicating that performance enhancement is linearly correlated to increasing fidelity. Few experiments involve the study of how effective computer based training systems are compared to prior training techniques or how to better use what we already have. Recently, one research project indicated that an

increase in environmental fidelity does not necessarily translate into an increase in navigational performance [GOER 98]. Research in the relationship of model fidelity to performance is essential to identifying the minimal and optimal levels of detail required to obtain spatial knowledge of a specific environment. Such research will provide information needed to furnish model designers and builders with a template for the construction of virtual worlds.

4. Army and DoD Relevance

Defining the levels of model fidelity and system exposure times required to provide a positive transfer of knowledge to the real world can save the Department of Defense (DoD) time, money, and other valuable resources. With the decreasing DoD force structure, the increasing quantity and types of missions the military is asked to perform, and a shrinking military budget, commanders need faster methods to train their forces while maintaining or enhancing their abilities to successfully accomplish their missions. Computers provide commanders with the opportunity to conduct time-compressed training as they perform multiple mission runs changing parameters on the fly and reducing the wear and tear on the terrain and equipment. The major focus of computing and mission preparation tools should be to provide commanders with improved tools to maximize the quality and quantity of training that can be conducted during a limited time frame without introducing negative training effects.

Virtual environments (VEs) may provide a cost-effective alternative to more traditional methods of training or mission preparation. The optimal computer training system has yet to be built for use in training dismounted forces. Even if an optimal interface and appropriate terrain model can be built, there is still the question of cost-effectiveness of such systems compared to traditional methods of model construction. In the past, the military has used mock-ups or other representations of an environment for mission preparation [GLIN 95] [FINN 97] [AMER 98]. Although these traditional model building methods are effective, they can be expensive, time consuming to construct, difficult to modify, labor intensive, and require large areas of terrain to be secured during construction and mission rehearsal (Chapter II, Section B.2).

Little research has been conducted and published to validate the usefulness of VEs in providing spatial knowledge of natural terrain. If an individual can gain the same or only slightly better spatial knowledge using a VE over using a two-dimensional map, photo, or sketch of the environment, then it may not be cost-effective to utilize virtual representations of actual terrain or buildings to acquire spatial knowledge. It is possible that a VE may only be useful in training general navigational skills such as map reading, dead reckoning, terrain association, and route selection (Chapter II, Section C.1). Real-time VEs may be too complex to provide positive training transfer of spatial knowledge. If this is the case, a randomly generated VE may be more cost effective and just as efficient at training navigation skills as a virtual representation of an actual piece of terrain. Understanding the positive and negative effects of computer training and mission preparation systems will assist commanders in determining if and when they should use such systems.

Understanding the actual and desired effects of computer training systems is essential for the development of a valid set of parameters for building models designed to equip users with spatial knowledge of an environment. This will assist the Army and DoD simulations personnel in determining when the construction and use of these models will be beneficial to military forces. Such standards will help to alleviate the misallocation of time, money, and computer assets for missions that do not warrant the use of computer generated models. The parameters will also assist in providing a common frame of reference for which these agencies, contractors, and programmers can consult with each other during the development and modification of such models.

C. THESIS ORGANIZATION

This thesis is organized in the following manner: Chapter II explores the background of spatial knowledge acquisition, the use of VEs to gain spatial knowledge, and land navigation and orienteering techniques. Chapter III outlines the development of the computer model and its capabilities as well as the methodology for this experiment. Chapter IV analyzes the data collected and discusses the results of the experiment. Chapter V provides the conclusions explaining the importance of the research and recommended areas for future research.

There are seventeen appendices to this thesis that provide experimental outlines, listing of research materials, course layout, participant instructions, and raw data from the experiment. The appendices also discuss route complexities based on the International Specification for Orienteering Maps (ISOM) and computer generated routes, outlines environmental comparisons of training conditions, and describes the navigational thought cycle.

II. BACKGROUND AND PREVIOUS WORK

A. SPATIAL KNOWLEDGE ACQUISITION

Spatial knowledge or spatial cognition is a mental representation of a real or virtual environment [WICK 92]. Figure 2.1 graphically displays Thorndyke's theory on how humans acquire spatial information to build a mental representation of their world [THOR 80]. In this model, the classifications of landmark, route, and survey knowledge are not mutually exclusive; knowledge at higher levels builds upon and augments knowledge gained from the preceding level(s).

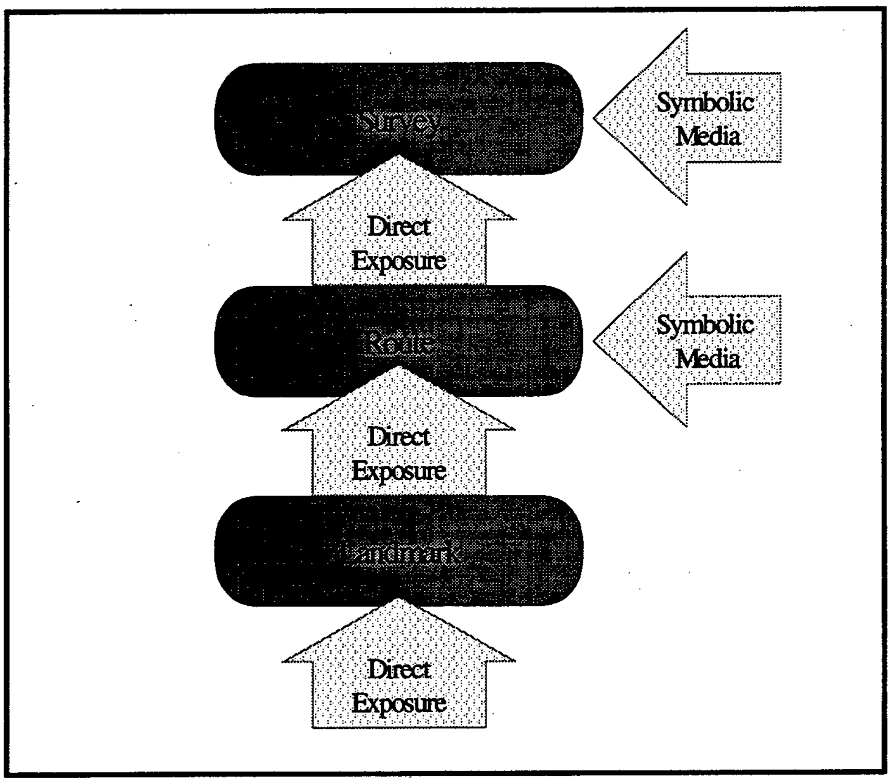


Figure 2.1. Navigation Knowledge.

Landmark knowledge is identified as the ability to recognize distinctive features associated with a specific location in the environment. This level of navigation knowledge is associated with the ability to store features, such as a specific hilltop or road intersection, in memory and recognizing it. Landmark knowledge is acquired through the direct observation of objects in the environment. It can also be gained through indirect observation of the objects in a medium such as a photograph. Successful

landmark knowledge is demonstrated by the ability to recognize individual locations or unique objects within an environment [DARK 95] [THOR 80].

Route knowledge is defined as the procedural knowledge required to navigate along a route or path between landmarks or distant locations [GOLL 91]. It is derived from the ability to expand landmark knowledge into a larger, more complex arrangement of linked objects. Route knowledge is based on an *egocentric* (inside-out) viewpoint and is demonstrated by the ability to move from one landmark to another along a prescribed path. Route knowledge can be gained through repeated exposure to an environment, map, or through simulated exposure to the environment via a medium such as video [GOLD 82].

Finally, *survey* (or configurational) *knowledge* is the highest level of spatial knowledge. It represents a map–like or top down mental encoding of the environment and is based on an *exocentric* (outside-in) viewpoint. This last form of spatial knowledge is usually gained through map study but, can also be gained through extensive and repeated exposure to the environment [THOR 80]. Survey knowledge can be demonstrated by an individual's ability to describe the relative locations and the distances between landmarks or by devising new routes between landmarks even though the person has never traveled a route between them [BANK 97].

B. VIRTUAL ENVIRONMENTS

1. Definitions

Real-time graphics are defined as models which provide network delays of less than 0.1 seconds and can render images at a minimum of 8 to 10 frames per second for relatively static environments and up to 60 images per second for environments where objects have a high frequency of motion [DURL 95].

The classification of *fidelity* is more qualitative than quantitative since there are no metric scales which allow us to explicitly define levels of fidelity. For this research, the definition of a high fidelity walkthrough terrain model is a model that represents lines of sight and terrain masking, provides realistic depictions of the vegetation and structures, and can provide a real-time interactive environment for the user (Figures 2.2 and 2.3).

Figure 2.2. Computer Model

Figure 2.3. Actual Photo

Landmark models are virtual representations of real world objects or locations that are easily identified, with defining characteristics, and are used by the participants as cues to navigate through the model. In Figures 2.2 and 2.3, the shack and poles are examples of landmark models. The term is devised for use in this thesis and derives from Thorndyke's theory of navigation [THOR 80].

2. Model Usage for Mission Planing and Preparation

For centuries, military units have conducted rehearsals in preparation for missions. Rehearsals were performed at all levels of command and took on many forms. Commanders utilized everything from checklists, sand table briefings, walk-through rehearsals using soldiers and open fields, video-taped runs of air corridors, to full fledged dress rehearsals utilizing complete mockups of the target area. The more extensive the rehearsal, the more resources and time were required. The more dangerous and complex the mission the more rehearsals were necessary for mission success.

During World War II, the Army Air Corps prepared its pilots for air raid missions over Japan by showing them films of the precise routes they would be flying over enemy territory. These films were not produced from satellite imagery or continuing over flights by American reconnaissance aircraft. Instead, the films were produced by the Air Corps film and production unit stationed in Hollywood, California [AMER 98]. The production unit built a model of the Island of Japan using over fifty ten foot square platforms, tons of plywood, modeling clay, burlap, and paint. Using reconnaissance photos of the island, crews worked twenty-four hours a day for weeks, expending thousands of man-hours, to construct and paint an exacting replica of the island so that camera crews could film bombing routes for pilots. In order to maintain security, the model was built and filmed entirely on a single sound stage that was placed off limits to everyone except the

personnel working on the project. Pilots routinely commented on how easy it was to recognize the terrain as they flew their missions because it was if they had been there before.

In 1970, the United States Air Force planned a raid on North Vietnam to rescue American prisoners of war (POWs) from the Son Tay prison near Hanoi, North Vietnam [GLIN 95]. The mission was extremely risky. It required a task force of Air Force, Navy, and Army Special Forces personnel to travel over 340 miles across enemy territory, attack an enemy held compound, pull out the POWs, and fly back across enemy territory to the safety of American bases. To prepare the forces for the assault on the compound, a replica of the prison was constructed of two-by-fours and target cloth. The compound was built to exact dimensions to allow helicopter crews to practice taking out the guard towers with side mounted machineguns and land a single aircraft in the compound for the insertion of Special Forces soldiers and the extraction of the prisoners. Due to the nature of the mission, security was of the utmost importance. Even though the camp replica was built and rehearsals were conducted in Florida, thousands of miles from Southeast Asia, the model had to be dismantled daily to prevent detection by the Soviet Satellite Cosmos 335. Because of this, rehearsals using the mockup were conducted at night. Before morning, the model was dismantled and all holes were covered to ensure that no information could be gathered by the satellite and passed to the North Vietnamese. The ground team conducted over 170 trial runs through the camp replica before final authorization was granted to execute the mission. All this effort required over 148 personnel to support and execute the operation. Although the prisoners had been removed from the prison prior to the conduct of the raid, the task force was able to execute the plan to exacting precision without the loss of one American life.

The Son Tay model was constructed with the assistance of an inconspicuous element of the CIA known as the Modeling Shop [FINN 97]. The three-dimensional modeling shop was located at the National Photographic Interpretation Center, in the Navy Yard. The section was established in 1964 to create three-dimensional models of key areas of the world to help planners and decision-makers with international policy decisions. The section operated for over thirty years and was finally replaced by computer generated modeling tools in 1997. Over the thirty-three years of the shop's

existence, the shop produced more than 862 products. These products include replicas of the U.S. Embassy in Iran and the Iranian Foreign Ministry, the Kremlin, sections of the city of Tehran, Russian aircraft, a section of Kuwait City from the U.S. Embassy in Kuwait to the Persian Gulf shoreline, and many other U.S. embassies throughout the world.

The efforts to construct detailed models and maintain security for similar missions requires hundreds of thousands of man-hours and an untold number of assets. However, the need to conduct detailed rehearsals is essential for successful execution of any complex operation.

3. Prior Studies of Spatial Knowledge and Virtual Environments

In 1997, Bliss, et al studied the role of VE technology in acquiring spatial knowledge as outlined in Thorndyke's model [BLIS 97]. They asserted that the spatial knowledge gained by navigating through a VE was comparable to the knowledge gained by navigating through the actual environment. They examined 30 firefighters performing simulated rescue operations in an office building. The firefighters were broken down into three study groups. The first group was given a map of the building to study, the second group was provided a VE, and the final group, the control group, was sent into the environment with no prior training. As they predicted, the VE and map study groups out performed the control group in the task of navigating through the structure. The researchers concluded that landmark, route, and survey knowledge can be acquired through the use of a VE or map. Although the Bliss experiment's performance measures indicated that VEs can provide landmark and route knowledge, there were no performance measures nor any qualitative analysis which suggested survey knowledge could be attained from VEs.

Bliss' research did not show any significant difference in performance between the VE group and the map only group. This begs the question of why we should use a VE to obtain spatial knowledge if a map provides the same or similar comprehension. This question is best addressed by a study conducted by Chase in 1983 [CHAS 83]. Chase examined individuals who studied maps of an environment which they had never been exposed to, and a second group of individuals who had extensive exposure to the environment but, never studied a map. His research suggested that the individuals with

extensive exposure to the environment had better landmark and route knowledge. However, the map study group had better survey knowledge of the environment. Therefore, Chase concluded that repeated exposure to an environment provides route and landmark knowledge but, this experience does not necessarily translate into increased survey knowledge. As stated earlier, survey knowledge is often obtained through exposure to an exocentric view while route and landmark knowledge are normally gained through repeated exposure to the environment.

Wickens and Prevett showed that aviators who were exposed to an "immersive" viewpoint had better navigational performance over those who were given tethered or side views [WICK 95]. This is possibly due to the more natural representation or intuitive viewer interpretation based on the field of view [WICK 98]. Taking this into account along with the Chase experiment, it is possible that the combination of map study and VE exposure may provide the optimal solution for providing total spatial knowledge of an environment [CHAS 83].

Banker showed that individuals with intermediate land navigation skills could gain and transfer their spatial knowledge from a VE to a natural environment [BANK 97]. He studied three groups; a map only group, a map and non real-time VE group, and a control group who studied a map and the actual environment. None of the participants had any prior knowledge of the course, terrain, or map. Participants were give one hour to study the environment and plot their route through the environment before the map was taken away from them and they were required to navigate the real world course. With only a one-hour exposure time, Banker discovered that the VE showed a significant increase in performance for intermediate navigators only. He concluded that due to advanced navigators' abilities to extract vast amounts of information from the map, the VE was of no additional advantages to them. He further surmised that beginning navigators had reached information overload with all the materials provided and they were unable to separate the noise from the essential information.

Goerger, et al conducted a similar study to the Banker experiment using a complex man made environment [GOER 98]. They compared two groups; a map only study group to a map and VE study group. None of the participants had any prior exposure to the building or the floor plans. Each group was given thirty minutes to study

floor plans of the seven-story structure and a clue sheet (Figure 3.17). The VE group was also exposed to a high fidelity, real-time computer representation of the building during the thirty-minute study phase. The floor plans had the control points and a designated route marked in red. After the thirty-minute study phase, the floor plans were taken from the participants who were then escorted to the building for the testing phase. The results of the experiment showed the map only group significantly outperformed the VE group. The researchers concluded this was due to the short exposure time. They surmised the limited exposure time did not allow the VE group to resolve the exocentric differences between the floor plans and the virtual world. Furthermore, this did not allow participants to translate their knowledge of the environment from the maps to the VE to the real world. This indicates that performance on spatial knowledge tasks after brief exposure to a high fidelity, real-time VE does not always exceed results gained from traditional navigation training techniques [GOER 98].

Although it has been demonstrated that virtual worlds can be effective in providing some level of spatial knowledge, we are far from understanding which characteristics of a VE and its interface are most effective. A study by Witmer, et al investigates the issue of user interface [WITM 95]. They examined 64 college students navigating a large building. The participants were broken into three groups; those who received verbal directions on how to navigate through the building, those who explored a VE of the building, and those who explored the actual building. Results indicated that the real world participants outperformed the VE participants who in turn did better than the verbal study students. Although the VE group outperformed the verbal group, some VE participants did not perform well. Further analysis of the training data indicated that VE participants who became entangled in the model due to difficulties with the interface spent much of their time bouncing into walls, becoming disoriented, and subsequently made many wrong turns. These same individuals had difficulty navigating through the actual building. Although these are qualitative measures, the data indicates that a poor interface can lead to disorientation and diminish the overall training efficacy of the VE.

In other research, Williams, et al investigated active versus passive control during flight mission preparation [WILL 95]. The study compared individuals who passively observed a flight through a virtual world to those who actively controlled the flight of the

aircraft through the high fidelity flight simulator. The study indicated that those participants who controlled the rehearsal phase outperformed those who passively viewed the training flight. They concluded that the optimal VE designed to enhance spatial awareness would include active control by the user.

Based on these studies we can conclude that VEs are useful in providing landmark and route knowledge. Augmented with map study to provide survey knowledge, the two media can provide a powerful method for obtaining spatial knowledge of unfamiliar environments. To optimize the use of a VE, the interface must be transparent to the user while providing active control of the viewpoint. Optimal exposure durations and fidelity levels are still a questionable element of the VE.

4. Model Classifications

The first aspect that must be considered before building any model is its purpose. Requirements for building a three-dimensional architect's rendition of a building's blueprints and the requirements for building a real-time walk through model of the same structure are significantly different. The first may require only a wire frame or flat shaded polygons. The latter may require expanded coloring schemes and texturing to provide a realistic appearance. The architect's rendition may not be concerned with collision detection, the portrayal of furniture, sound effects, or independent moving entities in its VE, while the real-time walkthrough model may. All these factors determine the system requirements, the type and quantity of environment information required, the programming language, the tools, the file structure, and the procedural steps for the construction of the model.

Virtual environments have developed beyond the initial desert and overflight models produced in the early 1970's through the 1980's for the Department of Defense. Today's models have extended into the realm of complex natural environments. Throughout this thesis, the term "complex natural environment" is utilized. This classification of topography represents a piece of terrain at least one square kilometer in size which consists of vegetation and elevation changes that mask lines of sight and provide obstacles to cross country movement. To facilitate navigation, the terrain must have numerous distinctive landmarks. Finally, it possesses numerous paths, trails, or

roads that provide opportunities for parallel navigation errors (Chapter IV, Section A.4.a).

Terrain models can be separated into four distinct categories based on the mode of travel through the environment. The four model categories are Dismounted Movement, Ground Vehicles, Rotary Wing Aircraft, and Fixed Wing Aircraft (Figure 2.4) [SULL 98]. Each of these categories requires a lucid level of fidelity or combinations of levels-of-detail (LODs) that must be considered before the start of model construction.

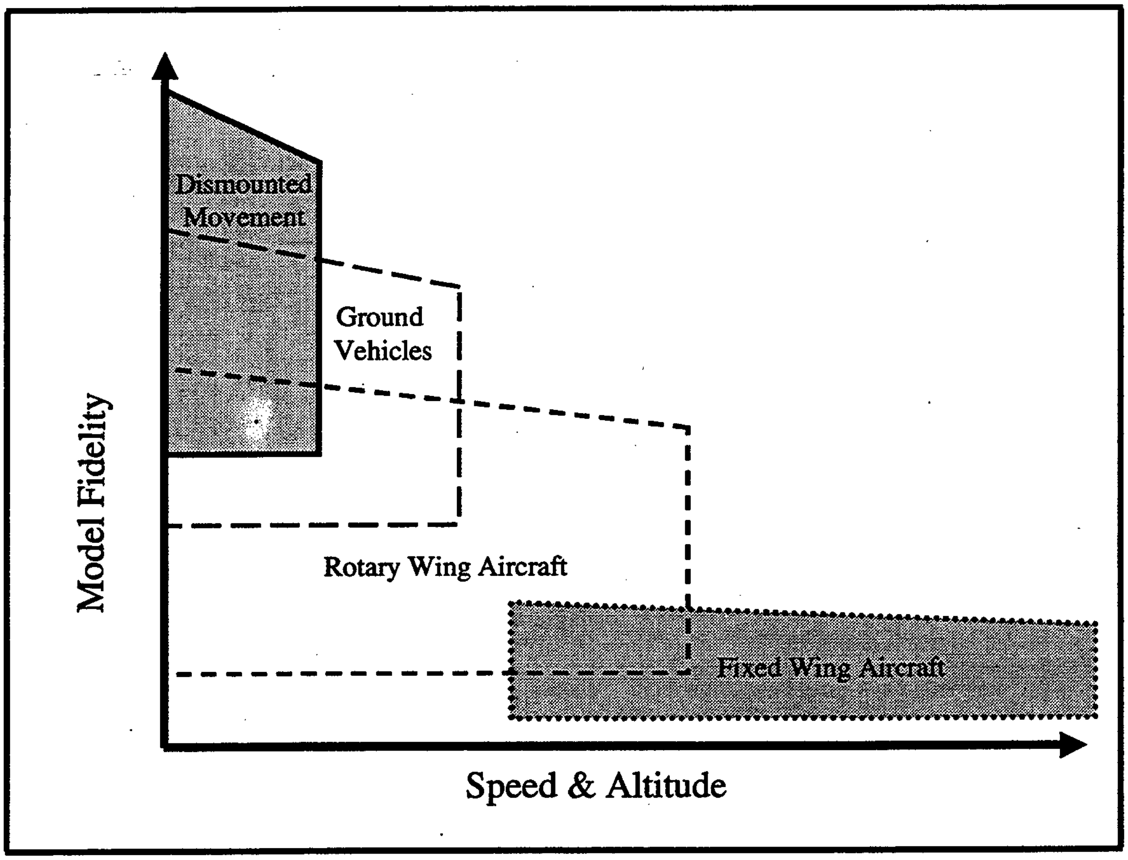


Figure 2.4. Fidelity vs Mode of Travel

The first category is the Fixed Wing Aircraft Model. Jet aircraft simulators and overhead "God's eye" view are in this category of model that requires limited detail due to the speed and altitude of the viewer. Models of this category typically consist of aerial photos or satellite imagery placed over elevation data. Distinguishing landmarks such as cities, lakes, major roads, valleys, and large landmasses facilitate navigation through this type of environment.

The Rotary Wing Aircraft Model is used in helicopter trainers and "pop-up" views. This model requires enough detail to distinguish groups of trees and buildings, as speeds are reduced to less than 100-mph and altitudes less then 200 feet. A model of this type will combine aspects of models from the higher resolution category Ground Vehicle Models with those of the lower resolution Fixed Wing Aircraft Model. Levels-of-detail (Chapter III, Section C) are used to smoothly page models in and out as the point of view moves between modes of travel. Navigating through this type of environment is facilitated by the user's increased ability to distinguish landmarks such as road and river intersections, small lakes, city blocks, draws, ridges, and hill masses. Additional items such as power and telephone lines, side roads, and major landmarks must be modeled in this environment. This increased fidelity assists in navigation and in providing the detail required allowing the aircraft to maneuver through the terrain in a realistic manner.

Surface level perspectives begin with the Ground Vehicle Model. Lines of sight must be preserved in order to provide the illusion the viewer in moving through the terrain. Realistic masking and unmasking of natural and man made landmarks are key to providing a representative model. This model also requires a higher level of detail as actual three-dimensional objects, such as buildings, statues, bridges, and signs are represented and distinguishable to the degree where they can be utilized as landmarks and navigational aids. General textures may be utilized to provide increased detail to the buildings and terrain providing a more realistic illustration. At speeds greater than ten miles per hour, texture fidelity can be reduced since actual details are blurred due to the velocity of the camera. This is based on the understanding that as views are overloaded with information or exposed to a high-density display, they filter the scene based on global and local perception [OLSO 70]. In such an environment, the individual will focus on objects which are unique or out of place with regard to the surrounding environment [FRIE 81].

The last category is the Dismounted Movement Model. This category requires the greatest level of detail of the four. The limited speeds of the individual moving through the model and the approximation of the individual to the objects in the model are the primary factors for increased resolution. In a fly or drive through scenario, the level of the trees and buildings, or the boundaries of roads, trails and clearings are the

customary limits of the camera. In a walkthrough environment, the user may need to infiltrate through the low ground or riverbeds, seek concealment in a tree line, pursue cover in a ditch or trench, or setup a patrol base in a thicket. Thus, much more knowledge of the actual environment is required and a greater level of detail must be represented. This is the foundation on which the model for this experiment was developed (Chapter III, Section C.).

Due to the general nature of the categories, the ever-increasing capabilities of computer hardware, and the expanding demands of the user, the borders between these categories are blurred and in many cases overlap. Further research must be conducted to solidify these boundaries and establish a set of general specifications to assist model developers and clients in determining what type of model is required. This can only be done through human experimentation. As computers and the virtual modeling community continue to move forward, the boundaries between these categories need not continue to shift towards increased fidelity requirements. This model can be solidified if category specifications are standardized based on complete understanding of user task requirements.

C. LAND NAVIGATION AND ORIENTEERING

1. Military Land Navigation

Efficient, well directed navigation is the process of moving through an environment in a manner in which the individual knows the start position, current position, destination, route to travel, and distance traversed. Navigation requires knowledge of location, direction, and destination, while having a means of travel through the environment [WICK 92]. It is also an evolving process. Navigation not only involves acquiring knowledge of and strategies to move through a space, it also requires modification of this metaknowledge of the environment as we move through the space and identify changes or inconsistencies with our mental representation [JUL 97]. Navigation can occur in, on, or through many different media such as land, sea, air, and space.

For military personnel, navigation plays a fundamental role in nearly any mission. For Marine and Army personnel, this is even more apparent. The Department of the

Army (DA) has recognized the importance of map reading and navigation skills for its personnel and has woven training requirements into its latest doctrine [FM21 93].

The Army implements a building block approach to training its people in navigation. Training starts at the initial indoctrination of personnel and continues at unit and Department of the Army training facilities. As soldiers move up the chain of command, the level of required expertise in navigation and map reading skills increases. Therefore, the DA has initiated land navigation in its basic training courses to ensure soldiers have the minimal skills for basic map reading and dead reckoning. Additional education occurs at the initial and intermediate leadership courses to refine and enhance navigation competence.

With a basic proficiency of map reading and dead reckoning, the Army feels their soldiers have the navigational foundation required to perform as team members during cross-country movement. However, military leaders require additional training that focuses on route selection and tactical movement techniques. These skills are trained at the unit and during basic leadership courses. Finally, the military also implements a more intense level of navigation and map reading instruction at the intermediate leadership and staff schools. This final level of navigation training is designed to ensure that mid level leaders and staff officers have the increased abilities to conduct detailed analysis of an area of operations. These personnel are expected to glean information from military maps, non-military maps, and aerial photos to develop an accurate and timely analysis of any area.

Basic skills taught in military land navigation training include map reading and use of an M2 or lensatic compass. Other navigational tools and field expedient methods for determining cardinal directions such as watch, star, and shadow-tip are also taught. Even the use of a global positioning system (GPS) for determining location has become an essential part of the curriculum. For cross-country movement, the military focuses on two basic land navigation techniques; dead reckoning and terrain association. These skills are perishable and must be continuously practiced to maintain proficiency.

Dead reckoning is the ability to navigate through terrain without the use of trails or intermediate landmarks. It consists of two fundamental steps. The first step consists of determining the direction of movement and the distance to travel. The second step

incorporates traversing the terrain utilizing a mechanism to determine direction of movement and a device to record the distance covered. This technique of navigation is normally associated with dismounted cross-country travel during limited visibility or through thickly vegetated environments.

The most difficult and valuable capability in military navigation is terrain association. This skill is used to visualize the features of the map and correlate them with the actual terrain features. The process of terrain association starts with aligning the map to the terrain. The second step is to determine one's location. This step is key to successful navigation. With knowledge of one's current location, a navigator can then determine the distance and direction to the destination. Without knowledge of one's location, the individual is doomed to roam aimlessly around the terrain until a fix is obtained.

Terrain association is also more forgiving than dead reckoning. Errors from terrain association can easily be resolved as the navigator reestablishes location and adjusts direction of travel. Errors with dead reckoning may not be discovered until the navigator has reached the prescribed distance. Then the actual location must be ascertained before a new direction of travel and distance to the intended destination can be determined. While utilizing terrain association, a navigator will focus on prominent terrain features, such as hilltops to guide direction of travel. The navigator may also use *handrails*, such as rivers or ridgelines to guide movement. Handrails are linear terrain features such as a river, road, trail, power line, or ridge that is parallel or congruent with the desired or most direct route that an individual follows as a guide [FM21 93].

Finally, to prevent over shooting the objective, a navigator utilizing terrain association will use a *catching feature*, such as a stream, to act as a limit of advance, stopping movement in a particular direction. A catching feature is a prominent piece of terrain used by navigators to indicate to the need to change direction or stop movement [FM21 93].

To assist with training and honing navigational skills, the military runs land navigation and orienteering courses. Orienteering is a competitive sport that combines land navigation and cross-country running. The Army divides orienteering into four

categories: route orienteering, line orienteering, cross-country orienteering, and score orienteering. Route orienteering is used for novice navigators. Soldiers follow behind a guide who takes them through the course. Soldiers are required to trace the route on their maps and circle the location of control points located along the route. Line orienteering consists of copying a pre-designated route onto one's own map. Soldiers then follow the prescribed route and circle the location of controls located along the route. At the completion of a route or line course, maps are compared to a master map for accuracy. Cross-country and score orienteering are two of the most common forms of what is known in the broader category of sport orienteering.

2. Sport Orienteering

Sport orienteering involves navigating through an environment utilizing a map, clue sheet (Figure 3.10), score card, and compass in order to find a series of three sided markers known as controls. Each face of the control marker is usually 12" by 12" and colored half international orange and half white (Figure 2.5). Barring no obstacles to observation, control point markers are designed to provide a participant with a recognizable view no matter which direction the control point is approached [LOWR 89].

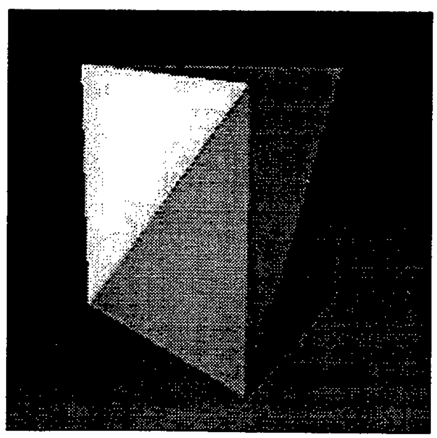


Figure 2.5. Control Marker

Most orienteering events are established in natural environments with multiple courses that provide varying degrees of difficulty. The length and the location of the control points determine the difficulty level of a course. The further apart and more technically demanding the placement of the control points, the higher the overall rating of

the course. Course levels are broken down by ability groups from beginner, advanced beginner, intermediate, and advanced competitors and are identified by a color-rating scheme. A white course, or beginner course, is typically 3km straight-line distance and is comprised of anywhere from seven to fifteen control points. An orange course, or advanced beginner course, is usually slightly longer with control points placed in more restrictive terrain than the white course.

Contestants are allowed to plan their own routes through the course based on their skills and experience. Some courses require competitors to find the controls in order (cross-country orienteering) while others allow contestants to find the controls in any order the participant desires (score orienteering) [FM21 93]. A circle on the map indicates the locations of the controls. The circles normally cover a 30 to 50 meter area and are further defined by descriptions on a clue sheet. An individual proves that they have visited a control by "punching" his or her score card with a punch which produces a distinctive pattern on the score card [BANK 97]. A combination of shortest time and number of control points found score the event. Each control point has a weight assigned to it based on its technical difficulty. The individual with the highest point total and fastest finish time is the winner.

Land navigation training affords researchers the ability to provide an adequate level of spatial knowledge through the use of proven training methods while implementing new training devices. Sport orienteering furnishes the testing platform for studying the spatial knowledge of individuals who have undergone land navigation training. The combination of the two makes for an excellent research opportunity.

III. METHODOLOGY

A. TEST ENVIRONMENT

A combination of military navigation and sports orienteering was used in the development of the methodology of this experiment. The course length, difficulty level, clue sheet, and marking system are comparable to an average orienteering orange course (Chapter II, Section C.2). The use of terminology, reliance on memory skills, and navigation techniques are more closely related to military land navigation.

The orienteering course is established on a 1.2km by .7km piece of terrain.[1] The terrain is located on the central coast of California in the former training area of the recently closed Fort Ord. The terrain is populated with outhouse facilities, shacks, pavilions, telephone lines, and a criss-crosseded trail and road network. Elevation varies from 90m to 123.4m above sea level. The limited yet distinctive changes in elevation provided a course that was neither a test of athletic ability nor a flat featureless environment.

The vegetation on the terrain can be broken down into three distinct categories; perennial grasslands, oak forest, and maritime chaparral. Perennial grasslands cover about one fifth of the course and are characterized by knee to waist high grasses and some widely scattered oak trees and underbrush. These areas have excellent visibility and possess limited obstacles to cross-country movement. The second category is the oak forest that makes up nearly forty percent of the course. This terrain is populated with inland or coast live oaks that vary in height from 25 to 45 feet. Inland oaks often have canopies that reach all the way to the ground creating mobility as well as visibility obstacles. The woodland varies in density and undergrowth allowing some areas to be easily traversed. Other areas are thick with vegetation or contain large quantities of poison oak making cross-country traversal more difficult.

The final category is maritime chaparral, which makes up forty percent of the course. Chaparral tends to grow in dense uniform thickets and has abrasive characteristics which create a considerable barrier to cross-country movement. Since cross-country movement through these areas is not recommended, walking around, as

[1] The dimensions of New York City's Central Park are approximately 0.9km by 4.2km which is four times the size of this model [MAP 98].

opposed to attempting to battle through, is the best way to negotiate these areas.

Due to its use as an active duty Army installation for much of this century, the area is criss-crosseded with a network of paths, trails, and minor roads. In conjunction with the occasional man-made structures listed above, the trails allow for the creation of a course rich in landmarks with many opportunities for the navigator to make parallel and mirror errors [BANK 97]. Parallel errors occur when individuals are not on their planned route or desired location but, on a route that runs parallel to the intended route or similar location within the environment. This occurs because of the ambiguities of the environment, which allow individuals to make mistakes without realizing their errors. A mirror error happens when a participant reaches a decision point, is faced with multiple options, and chooses the wrong one. For example, the participant comes to a fork in the road where he originally planed to take the right fork but, instead takes the left fork.

B. MAP AND COURSE DEVELOPMENT

MAJ William Banker utilizing the ISOM [INTE 90] developed the course map (Appendix F.3) [BANK 97]. Banker used a 1993 digitized aerial photograph of Fort Ord to provide the general outline of the environment. He also conducted ground reconnaissance to categorize the terrain and identify features not visible in the photo. The map was field checked by MAJ Banker in May of 1997 and by CPT Goerger in May of 1998. The scale of the map is 1:5,000. Traditional military operations maps use 1:25,000 or 1:50,000 scale maps. Competition orienteering maps are usually produced at a scale of 1:15,000. The higher resolution map for this course provided an extremely accurate depiction of the terrain. Trails and features down to two meters in diameter could be represented on this map. This afforded participants numerous landmarks and paths from which to plan their routes. The unconventional scale of the map may cause problems with discerning distance while the orienteering symbols and terrain features may cause participants unfamiliar with such terminology some confusion. To assist participants in overcoming these problems, a legend describing each symbol and color code as well as a distance scale are attached to the top of the map.

The course begins at the intersection of Gigling and Watkin's Gate roads and extends to the southwest. It consists of a starting point and nine control points. The control points were placed in accordance with the standards for a traditional orienteering

orange course. This means none of the control points are located on trails or roads. This ensures that participants will not merely stumble across control points and requires all participants to conduct some cross-country movement. The placement of control points allows for numerous routes to each location while limiting the possibilities for revisitation of previously traveled routes [BANK 97]. No extraneous or false control points are located on the course.

Participants are required to navigate through the control points in order. The straight-line distance between the control points is 2070m. Planning a very conservative route which sticks as close as possible to the roads and trails, a participant can plan a route in excess of 4560m or 2.85 miles. The course is designed to test memory and navigation skills while limiting the physical skills required to complete the course.

C. MODEL DEVELOPMENT

The model is a real time replica of the test environment and was developed based on the aerial photograph, course map, and ground reconnaissance. It was created on a SiliconGraphics Industry's (SGI) Onyx Reality Engine-2 workstation (Table 3.1).

Parameter	***Value***
Machine Type	SGI Onyx Infinite Reality
# Processors	4
Processor Speed	194 MHz IP25
Processor Type (CPU)	MIPS R10000; Chip Revision 2.5
Processor Type (FPU)	MIPS R10010; Chip Revision 0.0
Main Memory	256 Mbytes
Texture Memory	4 Mbytes
Graphics Pipe	RealityEngineII

Table 3.1. Machine Characteristics

While moving through the model at six to ten miles an hour, the system generates 34,360 plus triangles at 10Hz utilizing only one processor.[2] The model was developed on an SGI graphics workstation in anticipation that within two to three years, graphics

[2] The terrain model with all attachments consist of over 50,850 polygons (18,336 terrain polygons; 14,690 billboards at two polygons each; 65 structure models at an average of forty polygons each; two vehicles at 50 polygons each; 77 forest walls at two polygons each; 144 (+) roads, trails, paths, & trench line sections at two polygons each).

workstations costing ten to twenty thousand dollars and possible high end personal computers will be able to run a model of similar complexity at comparable rates of performance.

OpenGL and IrisGL are the substructure languages for some comprehensive development tools such as Multigen and Corypheaus's Designer Workbench, EasyTerrain, and EasyScene. A combination of Multigen and the Corypheaus tools were used in the development of the model.

Dismounted movement models [SULL 98], which replicate cross-country movement through rough terrain, require elevation accuracy to the nearest meter or better to represent ditches and holes. Model elevations are acquired from Digital Terrain Elevation Data (DTED) repositories. The experiment's model consists of DTED-2 data modified using Microsoft Excel to create DTED-5, one elevation post every meter. As part of his research in model building in 1997, MAJ William Banker made these modifications.

DTED is produced and distributed by the Department of Defense's National Imagery and Mapping Agency (NIMA) and comes in Level 0 through Level 5. DTED Level 1 (DTED-1) is one elevation post for every 100 meters and Level 2 DTED (DTED-2) is one elevation post for every 30 meters. Both DTED-1 and DTED-2 are 90 percent accurate to +/- 30 meters. Levels 3 - 5 are classified and only available to qualifying agencies and personnel. DTED-1 is available to the general public for the continental U.S., Alaska, Hawaii, Puerto Rico, and the Virgin Islands [EART 95].

Levels-of-detail (LODs) are utilized to specify at what resolution a section of terrain is rendered. When a model is created, sectors are established to help with the computer's culling process by identify what items should be displayed with respect to the location of the viewpoint. Sectors are established in a database as rectangular sections of terrain where the size of the sectors is based on the distances established for the LODs. These sectors are tiled together to create a grid. The sector where the viewpoint is located is displayed at the highest level of resolution and adjacent sectors are displayed at the next level of resolution. The further the sector is away from the point of view, the lower its level of resolution (Figure 3.1).

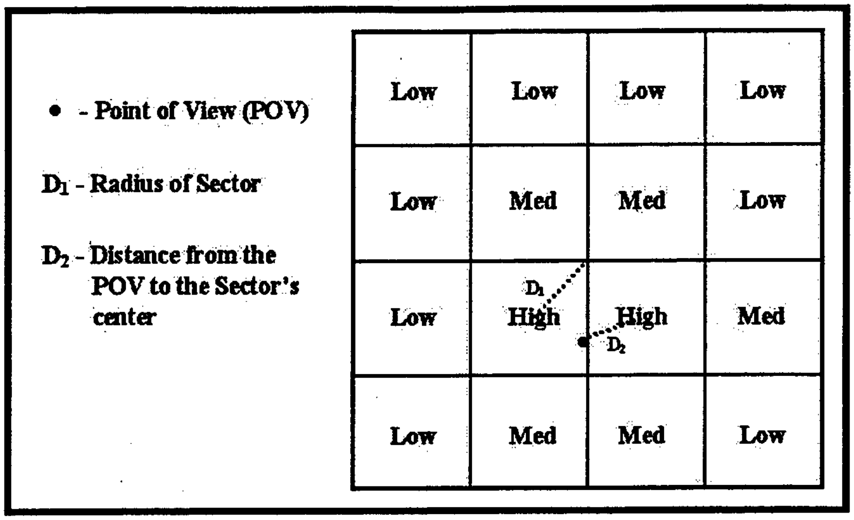


Figure 3.1. LOD Sector Grid

As the viewpoint moves through the grid, sector resolution levels will switch to accommodate the new viewpoint position [VOGT 97]. Adjacent sectors are switched to the highest level of resolution when the distance between the point of view and the center of mass of the next sector (D_2) is equal to, or smaller than, the distance between the center of mass of a sector and one of its corners (D_1). The distance for LODs was determined utilizing the formula for the resolution angle of an object. This angle is based on an object's distance from the participant thus, [distance to the object = (size of the object / 2) / tan (resolution angle / 2)] [SCHI 82] [SPER 97].[3] On angles less then 10^{O}, Schiffman asserts that the visual angle does not need to be divided in half. The revised equation is [distance to the object = (size of the object) / tan (resolution angle)].

O'Kane illustrated the stages of target acquisition based on Johnson's bar pattern methodology [OKAN 95] [JOHN 58]. She describes how a potential target goes through four phases: find, detect, recognize, and identify. The last three phases have application in the graphics world. Detection is when an object can be discerned from its background, for example; there is an object on the hill. As we draw closer to the object it is recognized as its features are discernable enough to place it in a specific category; i.e. the

[3] Schiffman explains how to determine the visual angle of an object based on the size of and distance to the object. He uses the formula [tan (visual angle/2) = (size/(distance/2))]. Sperber states in his notes that the resolution angle, the angle at which two similar items are no longer distinguishable as different objects, is 1/60th of a degree or less.

object on the hill is a truck. Finally, we approach close enough to the object that we can identify it by resolving its unique features; i.e. the truck is a Ford F150. The closer we get to the object the greater the size of the object's visible angle is in our field of view. These distances and angles can be calculated using Johnson's bar pattern methodology [JOHN 58]. For more common military targets, the angles for detection, recognition, and identity have been calculated using Johnson's bar pattern method and are listed in mrads[4] in Dudzik's Electro-Optical Systems Design, Analysis, and Testing [DUDZ 93].

Utilizing the above formula and Dudzik's table for resolution factors for a soldier, distances were calculated for identification, recognition, and detection distance. The average soldier standing in open terrain on a clear day can be identified up to 234m. The same soldier is recognized as a human up to 492m away and can be detected at distances up to 1247m with the naked eye.[5]

The model has three LODs. The first change over point is placed at 150m, the second at 450m, and the final LOD extends out to infinity. If the model were larger, the third LOD change over point could have been placed at 2000m or the far clipping plane could be set at this limit. The LODs for this model were based on the abilities of the computer system to handle the model fluidly, the previously stated calculations, and the standard distances used in Army marksmanship. As discussed earlier, individual target silhouettes lose their identity at 230m. Humans are unrecognizable at 450m to 500m and are not detectable at distances greater than 1250m when viewed by the naked eye. The average rifleman classifies targets within 100m as close targets. Starting at 150m, targets are considered midrange [FM23 89]. Army sniper training routinely works within the 1000m range even with a 10x scope [FM23 94].[6] Utilizing the 450m (diagonal 636m) mark as the limit of recognition of a human, this was established as the switching point for the second and third LODs. Attempting to maintain square sectors and using the max range of close targets, the switching point for the first and second LODs was placed at

[4] 1 mrad equals 5.72958 x 10^{-2} degrees [BEYE 84].

[5] The same relative distances can be calculated using a combination of Schiffman's formula [SCHI 82], Sperber's resolution angle, and the MIL-STD-1472D's [SPER 89] 95^{th} percentile measurements. For the average adult male's interpupillar breadth (7.1cm), head height (14.5cm), and chest breadth (36.7cm), the average individual will not be able to distinguish a pair of human eyes at 244m, a head on a pair of shoulders at 498m, and the human stature at 1261m.

[6] When estimating range, a sniper will determine the distance to a 6-foot man measuring two mils as 1000m [FM23 94].

150m (diagonal 212m) (Figure 3.2). This created sectors which were 300m x 300m and placed the switching point for the last LOD at 750m (diagonal 1060m).

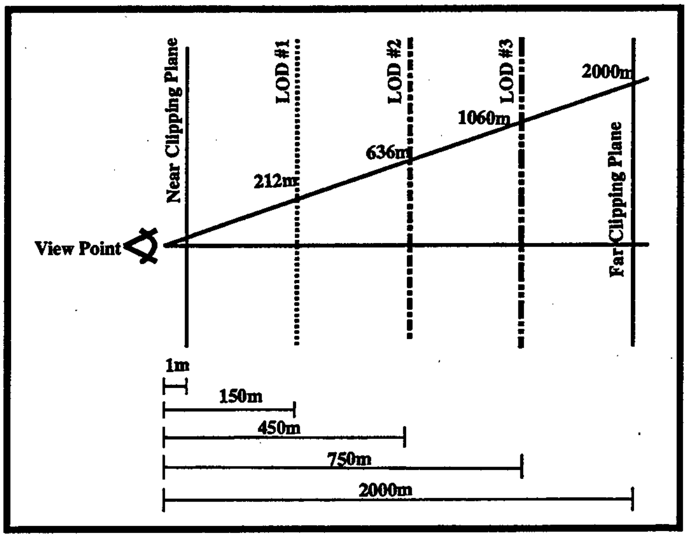


Figure 3.2. LOD Distances

Once the digital terrain data was converted into a terrain model and LODs, the model's surface was colored with earth tones reflective of the actual terrain. A black and white aerial photo texture was then attached to the terrain (Figure 3.3). This texture map was used to place roads and buildings and to define the boundaries of the wooded areas. The black and white photo was left on the final model to emulate shadow effects. The black and white photo allowed the base color of the model to bleed through the photo and give the terrain a more natural appearance.

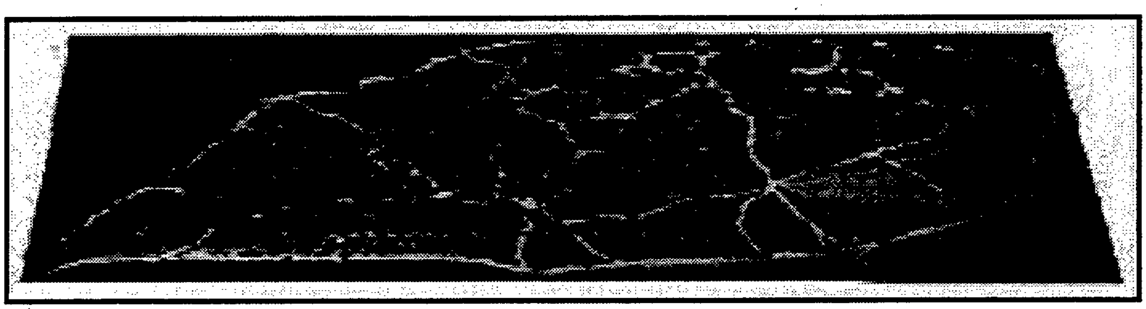


Figure 3.3. Elevation Model with Black and White Aerial Photo

After the terrain base was generated, landmark models were constructed and used to populate the terrain's surface. Landmark models are replications of structures that are distinctive and easily identifiable in the environment. Using photos and measurements of the structure, realistic replicas of the structure's exterior were developed. Telephone

poles, two small shacks, five individual outhouses, two distinct pavilions, two distinct types of cement pads, three separate rock piles, and sandbags were developed and used as landmark models. The aerial photo helped maintain alignment and object orientation when placing landmark models onto the terrain model.

Next, linear objects such as roads, trails, ditches, and power lines were placed. These linear objects helped establish boundaries and preserve proportions. With boundaries clearly defined, vegetation was added. Since most vegetation is complex in structure and liberally distributed, billboard textures (Figures 3.4 & 3.5) were utilized. The use of billboards greatly reduced the computational requirements for rendering the wooded areas. The billboards rotate with the movement of the camera, always providing the user with a perpendicular view of the object. Billboards provide the illusion of three-dimensional objects.

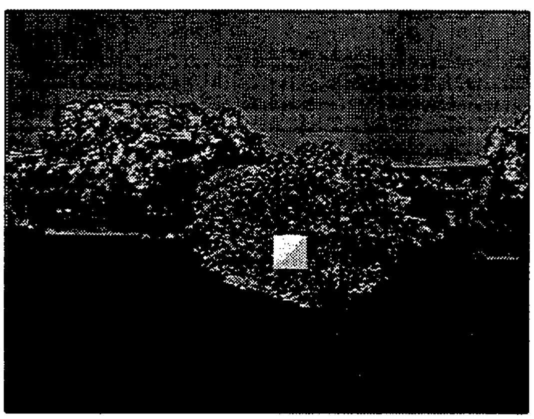


Figure 3.4. Textured Billboards

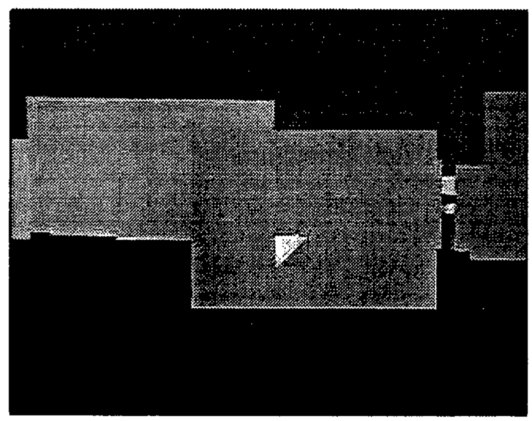


Figure 3.5. Untextured Billboards

Four distinct trees, three types of under brush, and two bushes were utilized in the model (Figure 3.6). An essential aspect of creating realistic billboards is the use of textures. Editing textures is more of an art than a science. Although there are many techniques for editing images, a commonly used methodology is to adjust colors and light levels, alter perspectives, correct image impurities, crop, size, save in an appropriate format, and final editing. These steps were completed utilizing Adobe Photoshop and MultiGen. The same textures used in the construction of the brush billboards were used in the development of walls that were intermixed with the billboards to provide the appearance of a forest.

Figure 3.6. Trees, Bushes, and Walls

The four tree billboards were randomly placed based on their size, largest to smallest, at a ratio of 40, 30, 20, and 10 percent respectively. The three distinct types of brush and two bushes were evenly mixed at 20 percent each. The three brush textures were also used to create three distinct wall types to represent forests at distances greater then 450 meters. A thick forest, approximately 25 percent of the model, has a dispersal of 15,000 trees and 10,000 undergrowth billboards per square kilometer. Moderate forests, 20 percent of the model, had 15,000 trees and 7,000 pieces of undergrowth per square kilometer. Forests with little to no undergrowth make up nearly 35 percent of the model and are covered with 7,000 trees and 500 pieces of undergrowth per square kilometer. About 10 percent of the model is covered with undergrowth at 10,000 plants per square kilometer. The rest of the terrain is a mixture of trails and open ground (Figure 3.7). In total, the model uses 34 textures and 9 billboards to populate the environment. The final model contains: twenty-two telephone poles, two shacks, five outhouses, three pavilions, nine cement pads, three rock piles, two sand traps, a paved road, over 9,960m of dirt roads, trails, and paths, two trench lines, 200 plus sandbags, 77 forest walls, and over 14,690 billboard trees, bushes, and brush. Two military trucks, (HMMWV) were also added to the model. These vehicles were used to provide a common object as a reference to resolve issues of size and perspective (Chapter IV, Section B.12).

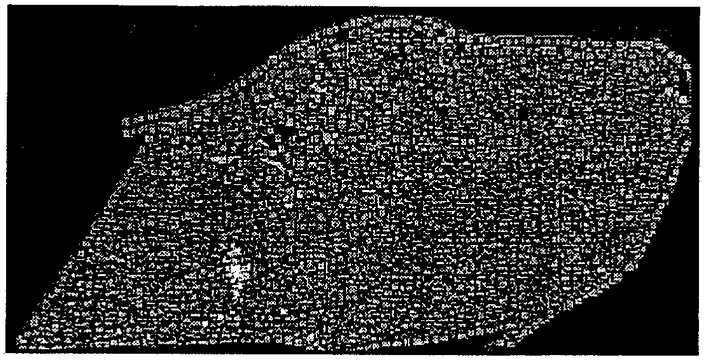


Figure 3.7. Model Populated with Objects

The LODs were determined for movement along the ground at a camera height of five feet eight inches. However, if a participant decides to travel along the terrain at an elevated level, he will experience a "popping" in and out of forest walls (Figure 3.8) and trees (Figure 3.9) as he crosses an LOD switch over point. Programmers use LODs to render closer objects at a level of higher detail than objects at greater distance. This is done by instructing the system to swap in images and structures with greater detail for closer objects and structures of lesser detail for further objects.

Figure 3.8. Wall Sketch

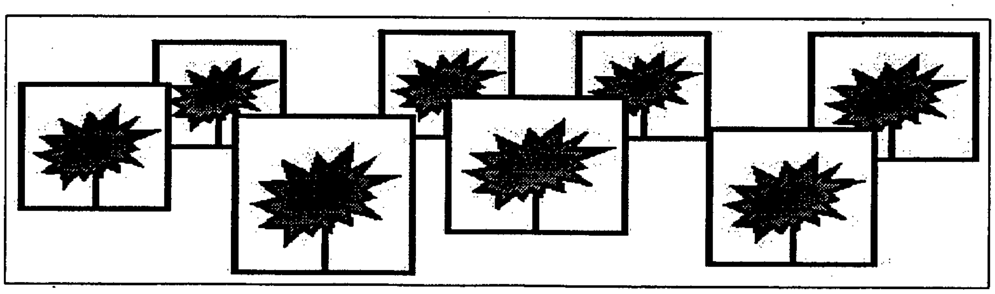


Figure 3.9. Trees Sketch

Depending on the distance and height of the viewpoint, the exchange of walls for independent billboard is visible and is commonly referred to as "popping". To alleviate this popping, the model may require dynamic LODs that change depending on the camera's distance above the ground. Additional LODs can be added which allow the modeler to slowly thin the trees out at different distances and makes the popping more understated. These options can be computationally expensive. To reduce model complexity, these features were not implemented in this model.

When viewing forest walls from an elevated position, the user can gain a false sense of vegetation density because of the lack of vegetation behind the walls (Figure 3.10). Placing a canopy over the top of the forest walls to represent wooded terrain can curtail this misperception. To reduce the amount of texture memory used for this model, forest canopies were not implemented in this model.

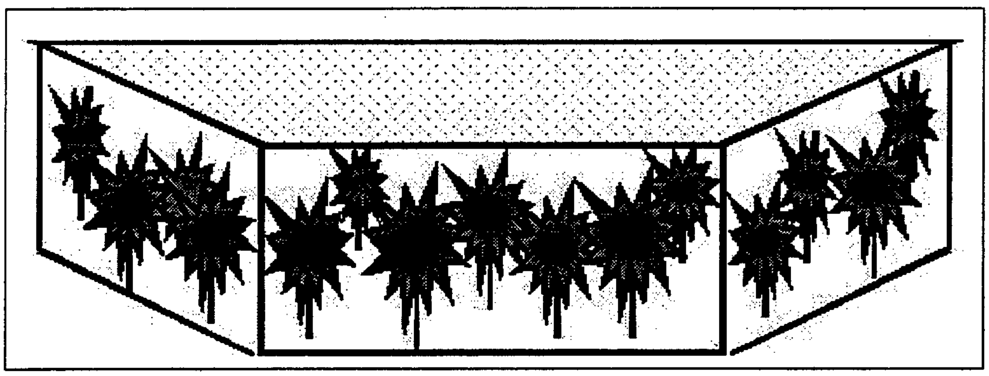


Figure 3.10. Elevated Wall Sketch

Once the terrain, structures, and vegetation were assembled and in place, the basic model was complete and the interface was developed. Utilizing the Coryphaeus EasyScene and API tools, an interface was developed to allow the model to be explored and the environmental conditions to be modified (Appendix P). Utilizing the BG Systems FlyBox (Figure 3.11) and a standard 124 key keyboard, participants were able to move through the environment at speeds of up to 10 miles an hour with viewpoints fixed at five feet eight inches or fifteen meters above the ground. Environmental conditions could be set for one of six conditions: sunny, cloudy, stormy, dawn, dusk, or midnight.

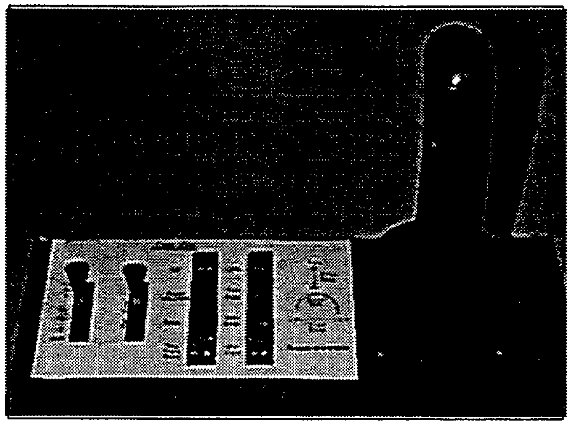


Figure 3.11. BG Systems FlyBox

The BG System FlyBox joystick is used as the main interface because it provides the participant with a compact set of instruments that can be manipulated utilizing only two hands without requiring an individual to have the dexterity required to use a keyboard. The joystick provides six degrees of freedom. This allows the participant to maneuver the viewpoint forward and back using a side lever and orient the camera's pitch and rotation as well as the movement heading using the joystick. The automatic centering feature of the joystick ensures the aligning of an individual's field of view with the direction of movement when a participant releases the controls.

Participants can teleport the viewpoint to any of the nine checkpoints. If navigational assistance is needed the interface allows the user to have a top down view of the model from 1500 meters or a compass is displayed indicating direction of travel. If the compass is activated, all linear movement of the viewpoint is stopped, however the individual can still turn or pitch the camera view. The FlyBox joystick is programmed to allow an individual to turn the camera view left and right up to 90 degrees and pitch the camera view up or down between 0 and 23 degrees to see the skyline or ground. The rotation and pitch of the camera view can be activated while in a travel or stationary mode.

The model is displayed on three Mitsubishi Model VS-5071, 40-inch, rear-projection screens set in a semi-circular fashion, sixty-seven inches from the participant, providing the user with a 103° field of view (Figure 3.12). Participants are seated behind a table that supports the joystick interface. The table has enough room to hold all training

materials and doubles as a study station for the participant. This same area is used for in briefing all participants and processing paperwork for the experiment. The model display and workstation were separated from the lab by four-foot high wall dividers to provide privacy and reduce the noise from outside sources.

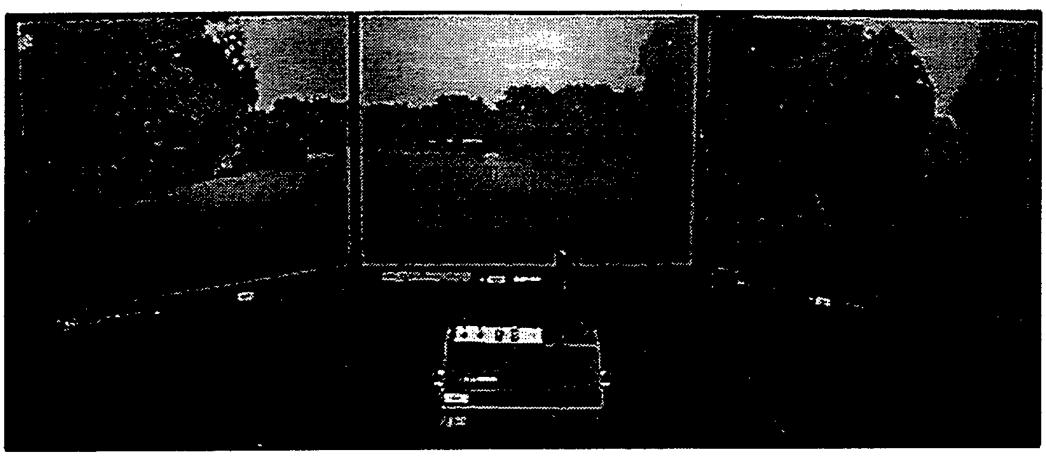


Figure 3.12. Model Display Configuration

The triple screen configuration is used to provide the participant with the peripheral cues required for navigation. While maneuvering through a piece of terrain, an individual views his position in the context of his surroundings. Without the additional terrain features provided on the periphery of an individual's vision, an individual is forced to delineate his position based on the 34.33° field of view rendered by a single screen. An example of the additional information provided to the individual is seen by comparing the single screen display in Figure 3.13 to the triple screen display of Figure 3.14. With the triple screen display, a participant is provided with traits such as the lone tree and trail on the left screen and the pavilion and telephone pole on the right screen. Moving through the environment using only one screen, the trees would have masked the telephone pole and pavilion to the right. If participants do not stop to look around at the intersection or rotate their heads during movement, they will not pick up these visual cues. These additional features help individuals to verify that their location is the trail intersection 80m to the southeast of Control Point 8 (Figure 3.15, Item A). Without these cues, participants may believe they are at the intersection 75m to the southwest of Control Point 8 (Figure 3.15, Item B), the intersection 125m south of

Control Point 9 (Figure 3.15, Item C), or the intersection 65m northwest of Control Point 8 (Figure 3.15, Item D).

Figure 3.13. Single Screen Display

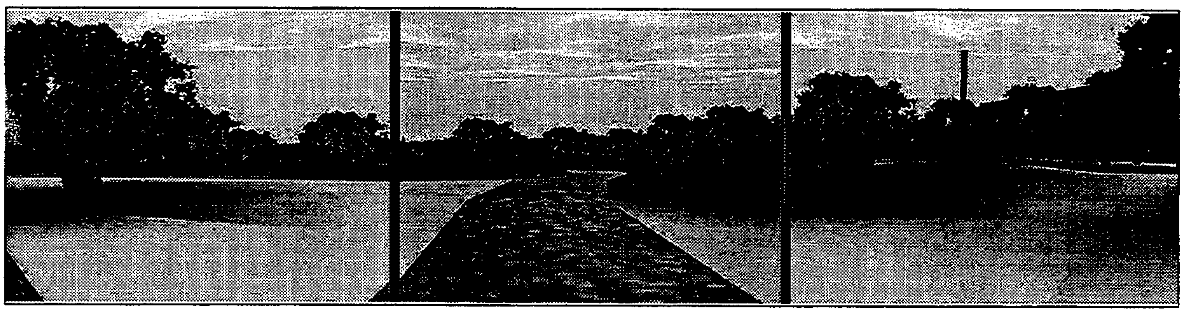


Figure 3.14. Three Screen Display

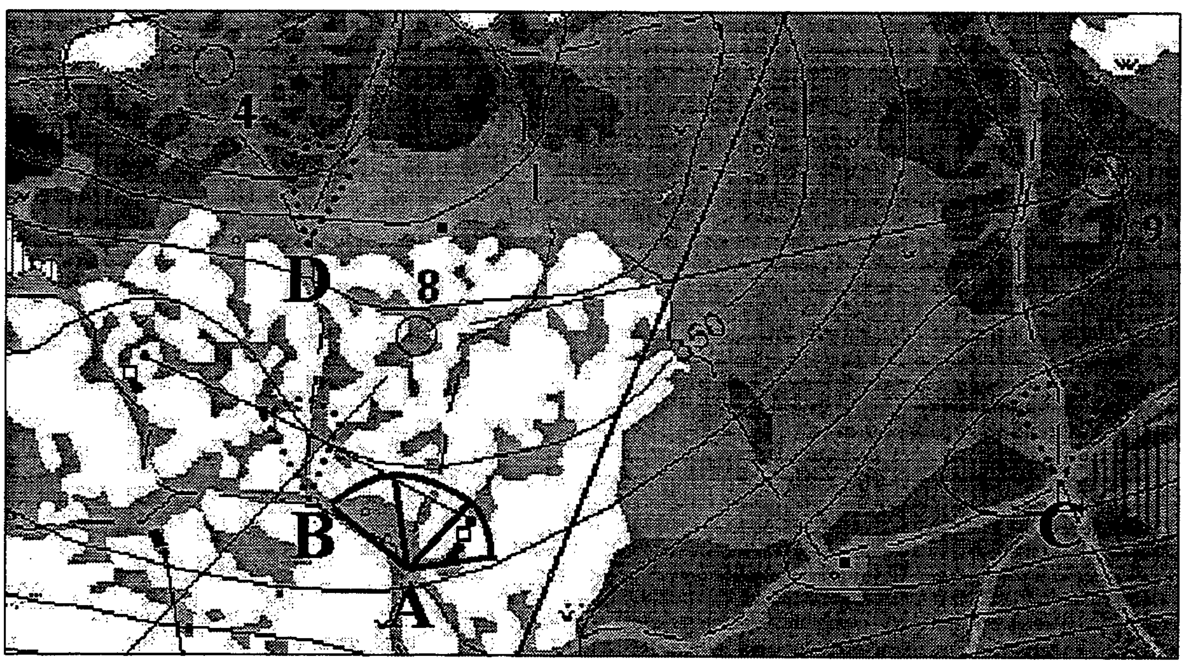


Figure 3.15. Map Excerpt for Three Screen Display

The effect of a three-screen configuration is even more apparent during movement. Figure 3.16 demonstrates how viewable time of a reference point increases as the field of view increases. During movement, individuals gauge their speed and position on how fast objects enter and leave their field of view. The greater the usable field of view the longer an object remains within view. If individuals use a reference point as a hand rail to keep them on course, the longer the reference point remains in view the more utility it provides. To demonstrate this, the graph in Figure 3.16 displays the curves for each field of view plotting velocity vs time. Using a generalized triangle, the angle α and distance $\boldsymbol{a}$ remain constant while the triangles remaining angles and sides $\boldsymbol{b}$ and $\boldsymbol{c}$ change as the viewpoint approaches the goal. Beginning movement at a distance of 212m from the goal β equals 10°. With a center screen field of view of 30°, the reference point will drop off the center screen at a distance of 151m (β equals 15°). Expanding the field of view to 100° by using a three-screen configuration, the reference point would appear on the side screen from 151m to 58.5m, β equals 50°.

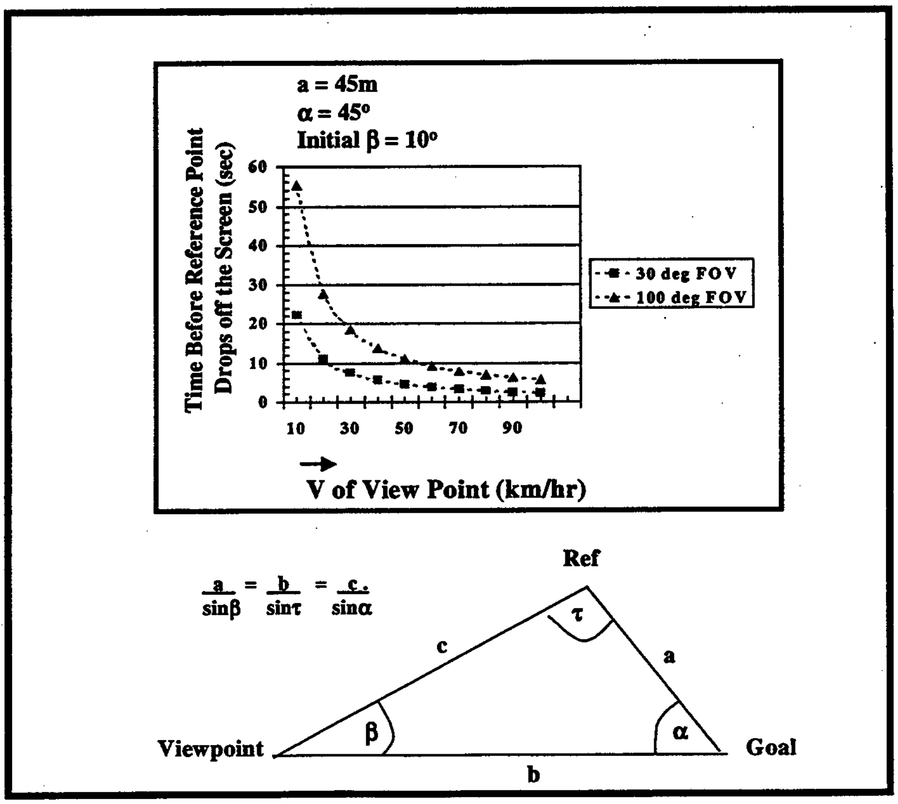


Figure 3.16. Reference Point Visibility Graph

Using the above distance, we can calculate the time a reference point is visible for each field of view by multiplying the distances by the rate of movement (Table 3.2). At lower velocities the difference in usable time is immense. The visible time of the reference point becomes more significant at greater speeds. This is due to the time required to identify a reference point in the environment and then locate it on the map. If the reference point quickly disappears from the center screen, it may not be recognized and utilized by the participant. Exposure on the peripheral screens may provide the seconds needed by the operator to use these reference points.

Velocity (km/hr)	*30° Field of View (sec)*	*100° Field of View (sec)*	*Difference (sec)*
1km/hr	222.14	553.53	331.39
10km/hr	22.21	55.35	33.14
20km/hr	11.11	27.68	16.57
30km/hr	7.40	18.45	11.05
40km/hr	5.55	13.84	8.29
50km/hr	4.44	11.07	6.63
60km/hr	3.7	9.23	5.53
70km/hr	3.17	7.91	4.74
80km/hr	2.78	6.92	4.14
90km/hr	2.47	6.15	3.68
100km/hr	2.22	5.54	3.32

Table 3.2. Visibility Graph Time Table

Peripheral cues used during stationary and active utilization of the model provides much needed information which will allow participants to disambiguate locations in the environment where parallel errors may occur.

D. PARTICIPANTS

Fifteen individuals, one female and fourteen males, served as participants in this experiment. The group consisted of one civilian and six Army, six Marine, and two Navy students from the Defense Language Institute (DLI) and the Naval Postgraduate School (NPS). The participants ranged in age from 28 to 39 with a mean age of 32. Participants had no prior knowledge of the evaluation area, nor any experience with the VE model. Participants were divided into one of three groups, "map only", "real-world", or "VE" treatment groups, based on the results of the Guilford-Zimmerman Spatial Orientation Aptitude Survey (GZ) (Appendix E.6). Participants received no monetary or academic compensation for their participation in the experiment.

Data collection occurred over a 71-day period. The extended time frame for data collection was to allow the grass to rejuvenate from the traffic created by participants moving through the terrain. An additional week's delay occurred due to an intense search of the area by law enforcement and military personnel looking for a missing child.

E. RESEARCH MONITORS

My assistant and myself acted as research monitors. Each monitor had gone through the course as a participant of MAJ William Banker's thesis experiment [BANK 97] or as a pilot participant for this experiment. Researchers followed a specified experimental outline (Appendix A) and a series of scripts (Appendix C) to ensure that each participant was presented with the same set of instructions, materials, and conditions. Whenever possible, participants were observed by both monitors. Research monitors carried additional equipment to ensure adequate supplies were on hand for the recording of information as well as for the safety of the participants (Appendix J).

F. TRAIN-UP

At the beginning of the experiment, participants were briefed on the requirements of the study and were asked to sign consent forms (Appendix D). After the initial brief, the Self Ability Evaluation (Appendix E.3), the Santa Barbara Sense-of-Direction Scale (Appendix E.4), and a map reading test (Appendix E.5) were administered. Next, the GZ test was given to measure the participants' ability to orient themselves in a 3-D environment. The result of the GZ test facilitated distribution of participants into the three treatment groups. The participants were evenly distributed based on above average and below average spatial orientation aptitude scores.

The first treatment group consisted of map only participants. These participants studied a map of the Fort Ord orienteering course. The second, or real world group, was given a map of the Fort Ord orienteering course and was allowed to explore the actual course. The third, or VE study group, was given the map and access to the real-time virtual environment of the course to study.

During the training phase of the experiment, all reasonable attempts were made to replicate the procedures of Banker's 1997 experiment. Each participant was given: a Participant's Task List (Appendix G), Map Marking Instructions (Appendix H), Course

Clue Sheet (Figure 3.17), a laminated map of the course (Appendix F), digital photos of the control points (Appendix I.2), scratch paper, pencil, and a red alcohol marker to draw the planned route. Virtual environment participants were given photos of the actual and virtual environment control points (Appendix I.3). Real world participants were also given a compass for their study phase. All participants were given one hour to study the material provided and plan their routes.

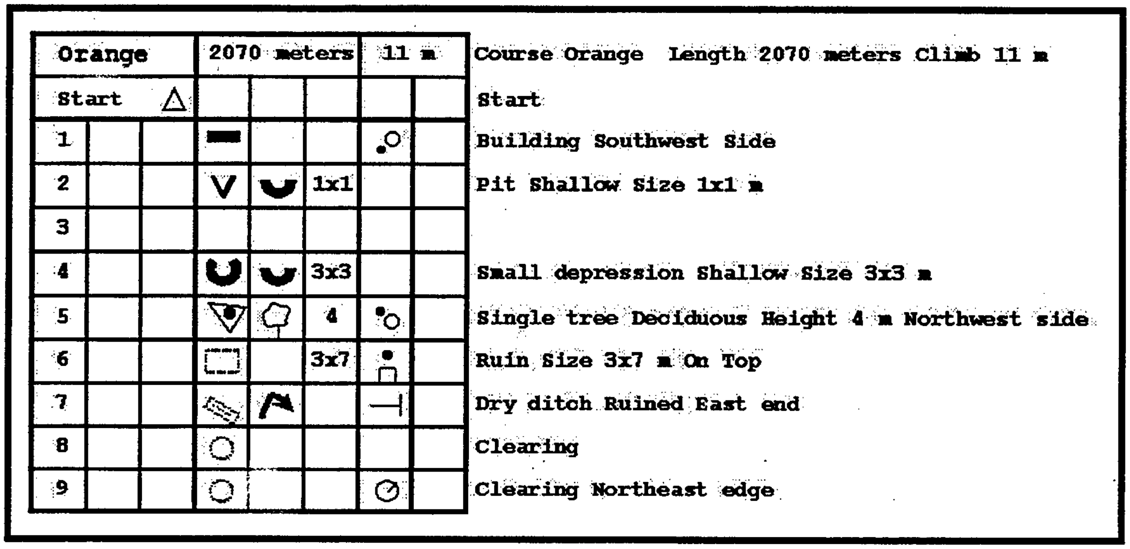


Figure 3.17. Course Clue Sheet

During the study phase, a research assistant observed each participant. Participant behavior was monitored and recorded on the participant's training phase worksheet (Appendix M.2) for future analysis. Participants were informed when they had 30 minutes and 10 minutes remaining.

G. DATA COLLECTION TECHNIQUES

Upon completion of the study phase, all study materials, except for the clue sheet, were collected from the participant. The participant was then taken directly to the starting point of the course by the shortest available route. Participants completed the evaluation phase via nine planned tasks, (Appendix B), and three unplanned tasks (Tasks 3.1, 5.1, and 10). The navigation course was divided into nine unequal legs, requiring participants to successfully negotiate nine checkpoints. The total straight-line distance of the course was 2070m.

The participants established planned routes during the train-up phase with the participants marking their intended route on the laminated map utilizing a red marker.

Participants' path knowledge was demonstrated by their ability to navigate from each succeeding checkpoint along their planned route. Accuracy was measured by calculating the number of deviations and the total distance deviated from the participant's planned route. Measurements were taken using a differential global positioning system (DGPS) and a Newton MessagePad 130 (Figure 3.18) which were carried by the participant.

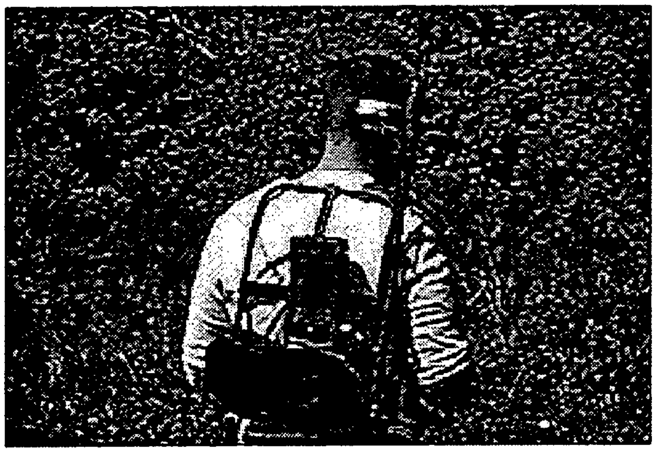


Figure 3.18. DGPS Backpack and MessagePad 130

The MessagePad 130 registered and stored a coordinate every five seconds as a participant moved and every five minutes while a participant was stationary. FieldWorker software was used to record the information for future analysis. Participants were allowed to deviate from their planned routes up to five meters while traveling on trails and fifteen meters during cross country movement before an error was assessed. This allowed the participants to explore the area and confirm their position without being penalized. Participants were also allowed to travel back and forth along their planned routes without penalty.

A helmet camera was used as a second means of data collection. The camera was a Hi8 camcorder bolted to the top of a hockey helmet (Figure 3.19). A sighting apparatus was fabricated and affixed to the helmet to allow the camera operator to determine if the participant was in the field of view. The camera's focus level was fixed at infinity and the camera operator stood at a distance of two or more meters from the participant to ensure the best possible image under these irregular conditions. The primary purpose of the helmet camera was to record map/compass checks validating the MessagePad's entries, and to provide data for behavioral analysis [BANK 97]. Participants were asked

to "think out load" (Appendix K) in order to provide insight to their thought process as they moved through the environment.

Figure 3.19. Helmet Camera

As a final means of data collection, monitors manually recorded any deviation from the participant's planned route and instances of map/compass checks on a black and white copy of the course map. This was done in the event of DGPS failure and was another means of verifying map/compass check locations and movement route. The monitors' knowledge of the test area, their experience in creating the VE, and their verification of the orienteering map allowed them to reliably record participant route deviations and map/compass check locations.

The experiment also examined survey knowledge by measuring (a) egocentric spatial knowledge using the "wheel" test and an unplanned route selection task, and (b) exocentric spatial knowledge using the "whiteboard" test (R. P Darken, personal communication, October 27, 1997). The wheel test was given to participants at checkpoints 2 and 4. The one-hour time limit was suspended during these tests. Monitors provided participants with a 12" x 12" plywood platform secured to a four-foot long 4x4 post (Figure 3.20). The post was fashioned to fit into a frame anchored in the ground near the control point. The frame was to ensure all participants are presented with the platform in the same location and orientation. On top of the platform, a seven-inch color wheel was attached. The wheel contains 16 different colored segments, with three pointers fixed to the center labeled SP, 2, and 9 for tasks at CP 2 (Figure 3.21) and labeled 1, 6, and 8 at CP 4. Control points were chosen to ensure that only one of the controls had been visited by the participant prior to the wheel test and none of the controls were either just visited or the control to which the participant was en route. This

prevented participants from viewing the controls in context with their planned route, thus measuring only route knowledge.

Figure 3.20. Wheel Test Platform

The wheel was affixed to a post, which allowed the participant to move freely around it, while the wheel maintained the same orientation for all participants. After positioning the wheel table to the south of the checkpoint, the monitor instructed the participant to use the wheel and its three pointers to indicate the directions to the appropriate control points. The color wheel with no bearing marks was chosen to force the participant to rely solely on his survey knowledge of the environment and not to confuse the wheel with a compass.

Monitors recorded actual bearings of each participant's pointer positions using the color-coded segments of the wheel. More accurate measurements were taken in the lab using a protractor and digital photos of the participant's color wheels. Also measured was the time it took the participant to complete the task and the participant's orientation while positioning the arrows. Monitors recorded observations and results on the participant's evaluation phase data sheet for future analysis (Appendix M.3). Upon completing the wheel test and before continuing on with the planned route, participants

were told how much time they had left to complete the course. Additional time checks were provided with 30 minutes and 10 minutes remaining.

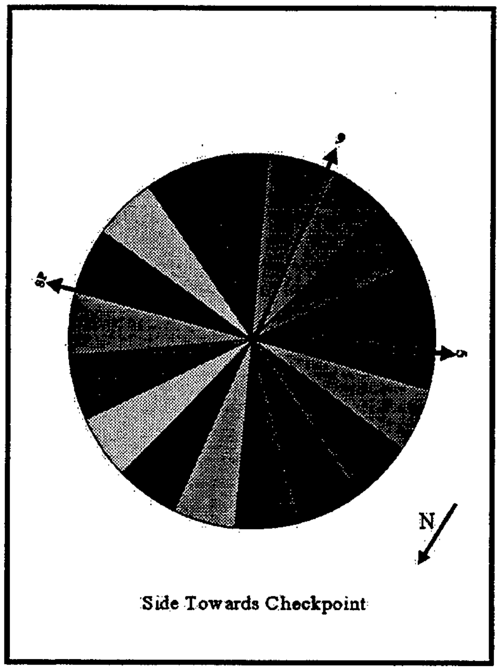


Figure 3.21. Wheel Test

After completing the planned course, participants were asked to indicate the direction of CP 4, describe the best route to CP 4, and finally to navigate to CP 4 using the most expedient route without referencing a map or compass (Appendix L.5). Participants were evaluated based on the route they traveled, the number of turns that lead them away from CP 4, and the distance they deviated from their planned route. After reaching CP 4, participants were finished with the navigation portion of the experiment.

Before leaving the course, one final unplanned test was administered. The whiteboard test measures a participant's exocentric survey knowledge of the environment. For this test, monitors provided participants with a white magnet board and ten magnets corresponding to the start point and the nine respective checkpoints. Researchers then instructed participants to place the magnets on the board in proper relation to each other, as the points would appear from a top-down view of the terrain (Figure 3.22). A digital photo was taken of the participant's magnet layout and later analyzed to measure the accuracy of the representation's relative bearings between

checkpoints and the relative distances of each leg of the course. An overall score is computed based on the total angular deviation compared to calculations derived from the orienteering map (Chapter IV, Section A.5.b).

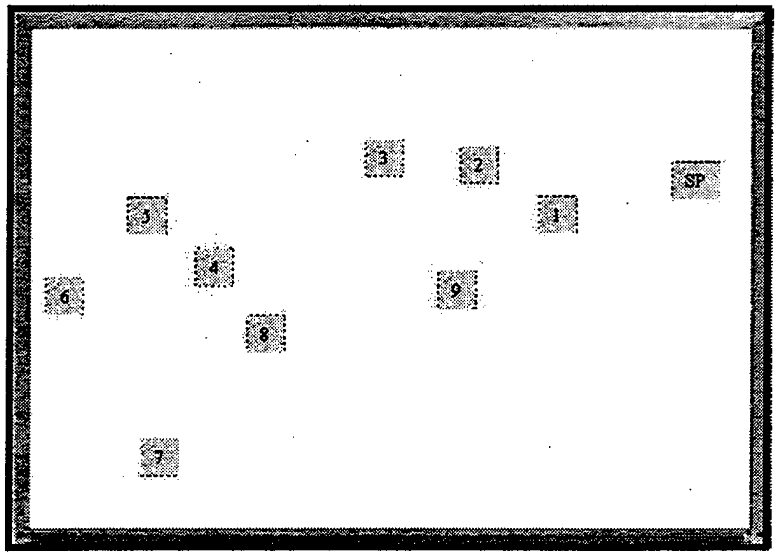


Figure 3.22. Whiteboard Test

After completing the whiteboard test, participants were taken back to NPS for the debriefing. During the debriefing, participants were asked to complete a questionnaire about their method of training and the course (Appendix A.7.f). Participants were also walked through the route they followed which was plotted on an aerial photograph of the course. The data exhibited on the photograph was exported from the MessagePad, converted into a format readable by ArcView software, and displayed on a 21" monitor. As they were taken through their actual route, participants were questioned on why they felt they had deviated from their planned routes.

During the execution of the course, participants were only required to wear the portable GPS backpack and carry their clue sheet. All other supplies, to include drinking water, were carried by the research monitors.

IV. ANALYSIS

A. RESULTS

1. General Information

The experiment is designed to test a primary and secondary hypothesis concerning the navigational knowledge of participants exposed to different training methods. To determine overall navigational performance, participants were evaluated on their route and survey knowledge of the environment while conducting an orienteering course through the target terrain.

a. Primary Hypothesis:

Given an hour exposure to training materials, participants with access to a real-time virtual environment will outperform those who are exposed to only a map and photos of the control points for the same time duration.

b. Secondary Hypothesis:

Given an hour exposure to training materials, participants with access to the real world will outperform those who are exposed to a real-time virtual environment of the same time duration.

c. Sub Hypotheses:

1) Route Knowledge

   a) Real world participants will commit fewer errors per control point attempted than VE participants. Virtual environment participants will commit fewer errors per control point attempted than map only participants.

   b) Real world participants will travel less distance per error before discovering and correcting their errors than VE participants. Virtual environment participants will travel less distance per error before discovering and correcting their errors than map only participants.

   c) Real world participants will perform fewer map and/or compass checks per control point attempted than VE participants. Virtual environment participants will perform fewer map and/or compass checks per control point attempted than map only participants.

2) Survey Knowledge

   a) Real world participants will have a smaller average delta angle on the wheel test than VE participants. Virtual environment participants will have a smaller average delta angle on the wheel test than map only participants.

   b) Real world participants will have a smaller average delta angle on the whiteboard test than VE participants. Virtual environment participants will have a smaller average delta angle on the whiteboard test than map only participants.

   c) Real world participants will have fewer errors during the execution of the unplanned route from CP9 to CP4 than VE participants. Virtual environment participants will have fewer errors during the execution of the unplanned route from CP9 to CP4 than map only participants.

2. Power Analysis

The tests conducted are two-way analysis of variances (ANOVAs) of study group and spatial aptitude (Guilford-Zimmerman). The sample size is fifteen participants. An □ of 0.05 was used, resulting in a power value (1-□) of 0.1095. As a result, the ability to detect alternative hypotheses is poor. This suggests that drawing any conclusions based exclusively on a failure to identify a positive effect on any factor is imprudent. A multiple analysis of variance (MANOVA) was not performed since each measure was analyzed to determine statistical significance for only one sub hypothesis. Simultaneity of effects was not considered critical.

In general, most of the graphs presented here are box plots on primary factors indicating the mean, standard deviation, and standard error. In addition, some graphs depict extreme data points as dots.

3. Normalization of Data

Many of the measurements used for analysis in this experiment occur over time and distance. Some participants were not given certain tests because they were unable to reach test locations prior to the one-hour time limit. To make participant data comparable, several measurements were normalized over the number of controls

attempted. This placed each participant's data in a rational format for correlative analysis.

4. Route Knowledge

Route knowledge is assessed by analyzing the errors committed, the average distance per error, and the average number of checks performed by each participant.

a. Errors

Five distinctive navigation errors were observed and recorded during the execution of the experiment. These errors were weighted and treated equally in the analysis of this data.

A *parallel error* occurs when participants mistake one piece of terrain for another or travel a parallel path more than 5m off their planned route when traveling along roads or trails and 15m off their planned route when traveling cross-country. An example of a parallel error is when an individual is located at an intersection west of his perceived location (Figure 4.1).

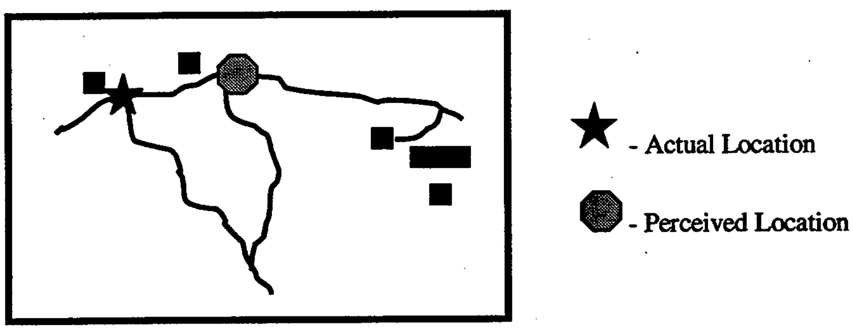


Figure 4.1. Parallel Error

Mirror errors occur when participants reach a decision point and mistakenly choose to travel the route that takes them in the mirror opposite direction of the correct path.

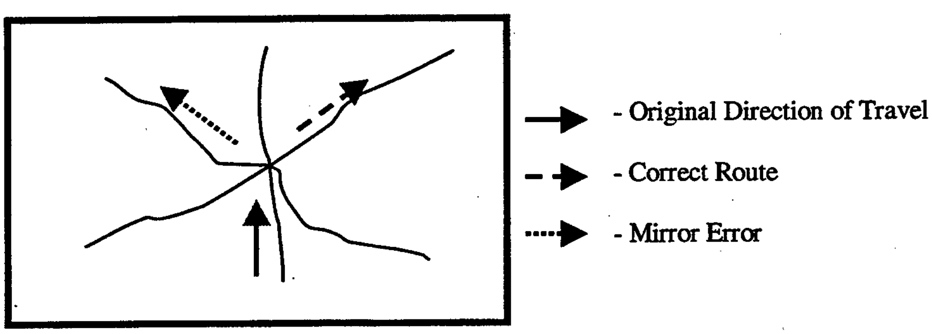


Figure 4.2. Mirror Error

Figure 4.2 is an example of a mirror error would be, if a participant comes to a fork in the road and mistakenly chooses the left trail when the right trail was the route originally intended.

Participants are assessed an *out-of-bounds* error when they travel outside the roads that enclose the course. The participants are not informed of their location or the proximity of other boundaries. The participants are only told that they have left the course area and must return to the other side of the boundary road. No additional distance error is recorded.

A *reorientation error* occurs if participants have been off their designated route for fifteen continuous minutes and are not making progress towards their intended control point. The participants are stopped, shown their location on the map, reoriented to the ground, and given sixty seconds to mark their new route to the intended control point. The distance from this location until the participant locates the correct control point is added to the parallel or mirror error which was at the origin of the participant's disorientation.

A *compound error* is assessed if participants commit a parallel or mirror error on the newly planned route resulting from an assessed reorientation error. The distance is measured and recorded for this error from the location where participants are more than 5m off their planned route when traveling along roads or trails and 15m off their planned route when traveling cross-country until they reacquire the newly planned route.

Parallel, mirror, and compound errors are weighted equally. Due to information being passed to the participant during the assessment of out-of-bounds and reorientation errors, they can be thought of as unrequested map checks. These errors are used in the calculations of the Map Check Scores (Chapter IV, Section A.4.c) instead of being used in determining the participants' error scores. This prevents the errors from having twice the impact on the participants' overall scores and is more representative of the event. For each leg of the course, each participant's errors were recorded and summed into a Leg Error Score. A participant's Normalized Average Error Score is the summation of the individual Leg Error Scores divided by the number of controls attempted (Appendix O.3.a).

Figure 4.3 shows Normalized Average Error Scores of all three treatments with a lower score indicating better performance. The map and real world conditions are approximately the same at 0.7 errors per attempt. The VE group lags behind with a group mean of 1.1. Also note the real world participants had a far greater variance indicating that while some participants had a higher performance others had exceptionally poor performance.

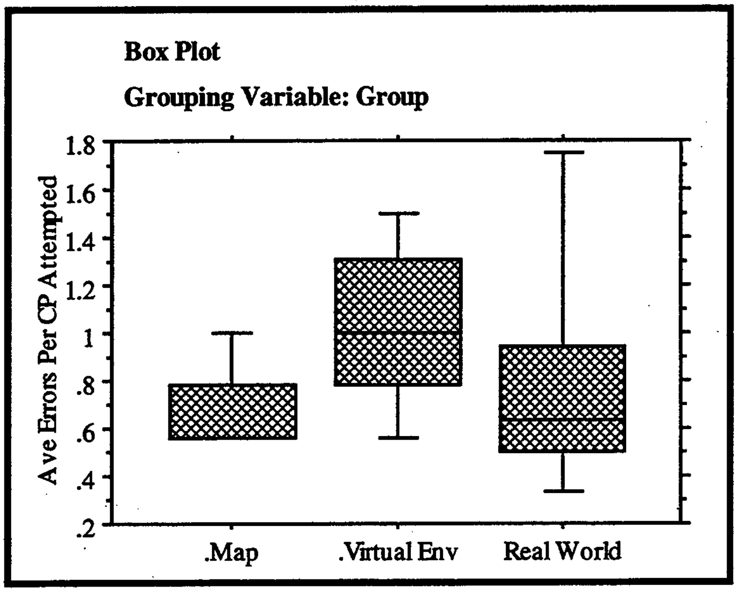


Figure 4.3. Interaction Box Plot for Error Per Controls Attempted (Group)

The means between groups are not statistically different, $\underline{F}(2,12) = 1.053$, $\underline{P} = .3789$. Direct observations suggest that map participants outperformed VE and real world participants by committing fewer errors per control attempted. Map participants appeared to follow their planned routes better indicating they had better route knowledge of the course. Real world and VE participants (VE1, VE3, RW3, and RW5) who made better progress during the training phase committed fewer errors per control attempt than those participants who made little progress during the training phase. This suggests that individuals who make it further in the environment during their exposure to a VE or the real world demonstrate better route knowledge by committing fewer errors. This also suggests that difficulties encountered during the training phase carried over to the execution phase of the experiment (Chapter IV, Section B.9).

b. Distance Traveled per Error

Determining how long it takes the participant to recognize and recover from the error is as important as identifying when a participant makes an error. To determine this, the distance the participant travels is measured from the point an error is committed until the participant returns to the planned route. These measurements are determined by comparing the participant's planned route to the data collected from the Global Positioning System. Both pieces of information are loaded into and displayed in ArcView on the aerial photo of the course. Using the ArcView measuring tool, measurements are then taken of any differences based on the route error criteria. The experiment parameters specified that measurements be taken from the location where participants are 5 or 15m respectively from their planned route until they reacquire their planned route was measured and recorded for this error. The measurements are summed and divided by the total number of errors to determine the average distance per error. These figures are computed for individual legs and the complete course for each participant resulting in the Leg Distance Per Error Score and the Distance Per Error Score (Appendix O.3.a). Dividing the average distance per error by the number of controls attempted results in the Normalized Average Distance Per Error.

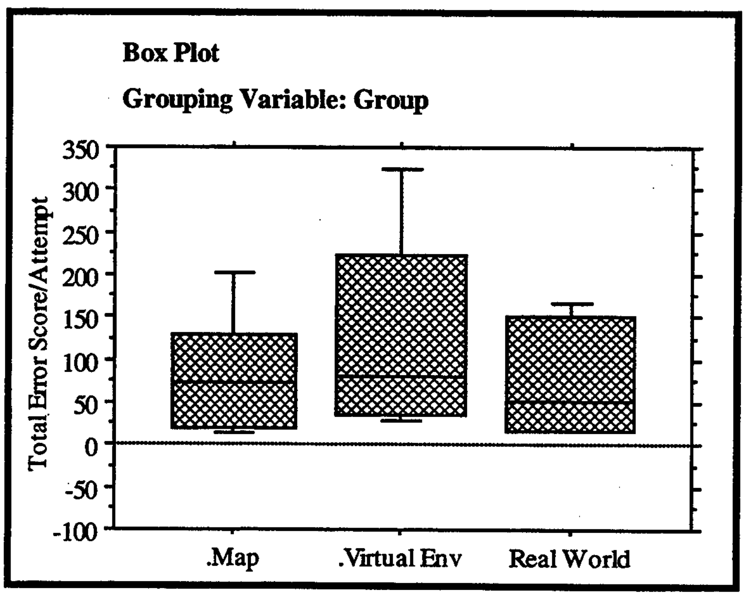


Figure 4.4. Interaction Box Plot for Normalized Average Distance Per Error (Group)

The Normalized Average Distance Per Errors of all three treatments with a lower score indicating better performance are shown in Figure 4.4. The map and real world conditions are approximately the same at 80m per error per attempt. The VE group lags behind with a group mean of 131m.

The means between groups showed no statistical difference, $\underline{F}(2,12) = .479$, $\underline{P} = .6305$. Direct observations indicate that real world and map participants outperformed VE participants by traveling less distance per error per control attempted. This implies that map and real world participants were equally adept at identifying errors and correcting them. Note that the VE participants had a far greater variance indicating that while some participants had a higher performance, one individual had exceptionally poor performance. Virtual Environment Participant #2 was an extreme outlier for distance measurements since the participant traveled over 3000m on his first error encircling the entire course (Appendix N, Figure N.63). After removing this participant from the analysis, results for all three groups are roughly identical, ($\underline{F}(2,11) = .003$, $\underline{P} = .9965$). This suggests that there is, in fact, no difference between groups when it comes to identifying that an error has been committed and being able to recover from an error (Figure 4.5).

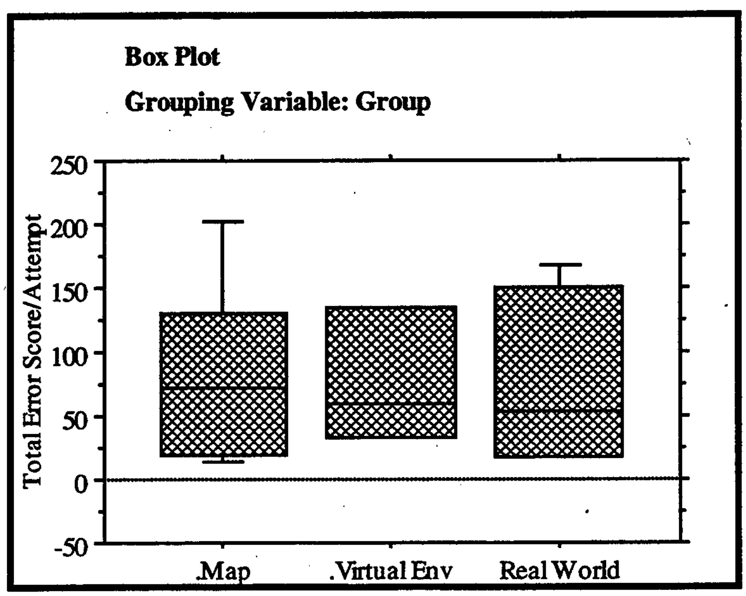


Figure 4:5. Modified Interaction Box Plot for Normalized Average Distance Per Error

c. Map and Compass Checks

Participants were allowed to request three distinct types of navigational checks while on the evaluation portion of the exercise. Each check was timed and recorded by research personnel on a black and white copy of the course map. Participants were allowed to request as many checks as they felt necessary for them to conduct the course. Participants were allowed to request consecutive checks if they need them. During a map check, participants were allowed to view the laminated map marked with their designated course for thirty seconds. For a compass check, participants were given an orienteering compass for thirty seconds. For a map and compass check, participants were given the laminated map marked with their designated course and an orienteering compass for sixty seconds. When not being used for a map and/or compass check, the research monitor maintained all materials.

Map and compass checks are weighted at 1.0. A combination map and compass check is weighted at 1.5 for the additional information that can be gathered utilizing the two in tandem. For a change of route, a participant is assessed a .5 weight against a map check. The penalty is assessed due to the information which can be gained while plotting the new route on the map, however a full penalty is not assessed since participants must have knowledge of their location and the environment if they wish to change their route. If participants misidentify their location and therefore plot a bad route from their current position, a parallel error is assessed as participants initiate movement from their current position. An out-of-bounds error is weighted at 2.0 because participants receive additional information from the research monitor who tells participants they have left the course boundaries. An out-of-bounds error also indicates that participants have lack of knowledge of their location with respect to the course. The reorientation error is weighted at 3.0 due to assistance provided by the research monitor who informs participants they are off their designated route and shows them exactly where they are on the map before the participants plot a new route to the intended control point.

Map Check Scores were calculated for each leg of the course and a Total Map Check Score was calculated by adding the individual leg scores. Dividing the Total Map Check Score by the number of controls attempted normalizes the value. This value is known as the Normalized Map Check Score (Appendix O.3.a). Figure 4.6 displays the

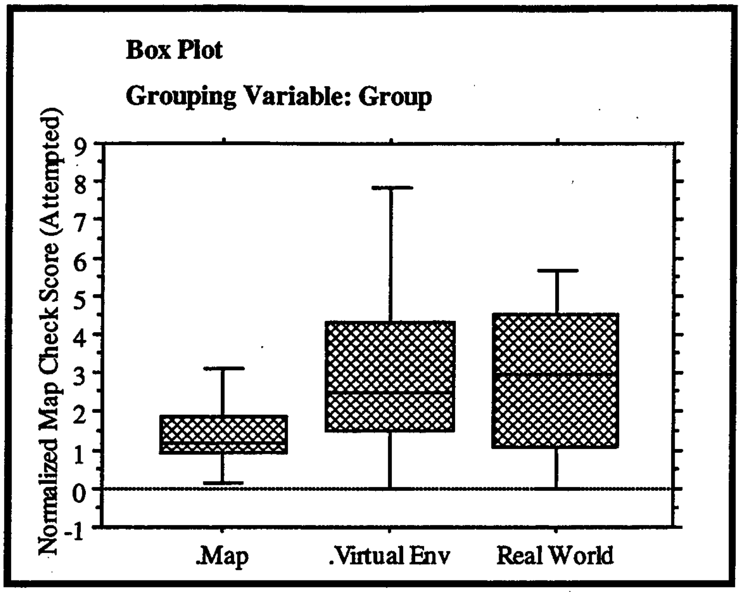


Figure 4.6. Interaction Box Plot for Normalized Map Check Score (Group) Normalized Map Check Scores of all three treatments with a lower score indicating better performance. The map condition outperformed the other two with a mean of roughly 1.5 checks per control attempt. The VE and real world conditions were relatively the same at approximately 3 checks. The means between groups are not statistically different, $\underline{F}(2,12) = .838$, $\underline{P} = .4564$. Direct observation indicates that the map only group participants performed less map and compass checks than VE and real world participants. This suggests that map only participants had more confidence in their memory and mental maps than the VE and real world participants who required more checks per control attempted to resolve differences in their mental maps and the actual environment. This is due to map participants concentrating solely on the map during the training phase which resulted in a better mental facsimile of the map.

5. Survey Knowledge

a. Wheel Test

Participants were tested twice using the wheel test (Chapter 3.E), once at Control Point 2 and again at Control Point 4. Digital photos of the participants' answers were compared to images of the correct answer. Measurements were taken of the angle variances. The participant's absolute values of the angle deviations are summed for each control point. Each participant's total angle deviation for Control Point 2 and Control Point 4 wheel test sites are used to determine the participant's egocentric survey

knowledge. The total angular differences are stored in Average Angular Difference CP2 and in Average Angular Difference CP4 receptively (Appendix O.4.b). Four participants were not administered the wheel test at CP4 since they failed to locate the control point. To compare scores across participants, Average Wheel Test Angular Variance scores are normalized by adding the absolute values of the angular differences and dividing the sum by the number of control points the participant identified, 3 or 6 control points.

The Average Wheel Test Angular Variances of all three conditions with a smaller deviation indicating better performance are shown in Figure 4.7. All three conditions are approximately the same at 26.5° per error per attempt. The means between groups showed no statistical difference, $\underline{F}(2,12) = .012$, $\underline{P} = .9879$. Direct observation suggests

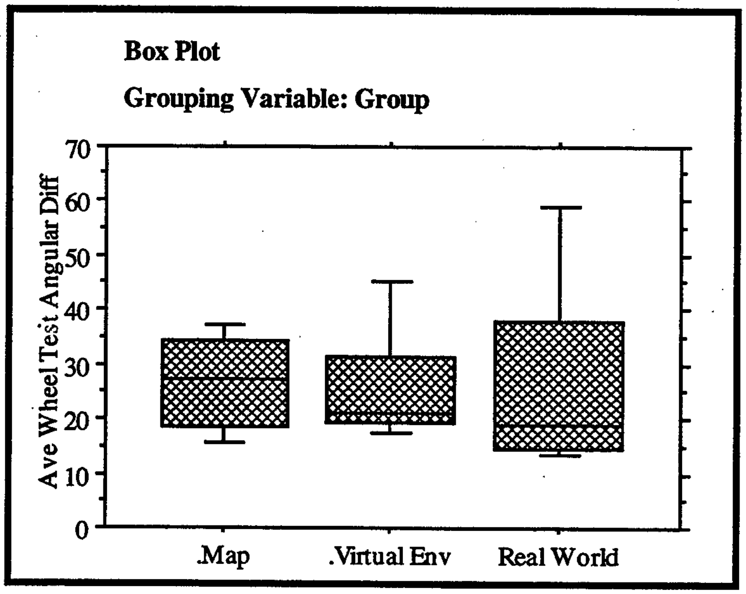


Figure 4.7. Interaction Box Plot for Average Wheel Test Angular Variance (Group)

that map and VE participants outperformed the real world group who had a larger standard deviation. This deviation indicates a greater variance amongst participants within this group with most participants performing well and some participants performing poorly. Without this variance, performance by real world participants may have shown better results. The two real world participants who had the greatest average angle variance (RW1 and RW4), took longer to perform the wheel test and found fewer control points than the other real world participants (Appendix O). This indicates they had less route and survey knowledge than their fellow real world participants.

b. Whiteboard Test

Each participant's Whiteboard (Chapter 3.E) results were analyzed to determine a participants exocentric survey knowledge. This was accomplished by calculating the angle differences between each control point. The angular variances were determined using a metric intended to normalize results for simple comparisons across participants. The technique begins with capturing results by taking a top down digital photo of each participant's Whiteboard. The image is down loaded to a PC and imported into Adobe PhotoShop. Once loaded into PhotoShop, the image imperfections are removed and the photo is squared. Using the PhotoShop navigator tool, "x" and "y" coordinates are taken for the center of each control point. The coordinates are fed into an Excel spreadsheet that calculates distance between successive control points (SP, 1, 2, 3, 4, 5, 6, 7, 8, 9, SP). Dividing each leg measurement by the sum total of all distances for each participant normalized the distances. The resulting normalized distance measurements are used in conjunction with the Pythagorean Theorem to calculate the angles between the successive control points. The resulting angles are compared to the actual angles between control points. The actual angles are calculated from the "x" and "y" coordinates from a digitized course map. The resulting variances and their absolute sums are provided along with participant Whiteboard coordinates and measurements in Appendix O.5. Sanitized participant Whiteboard images are provided in Appendix N.

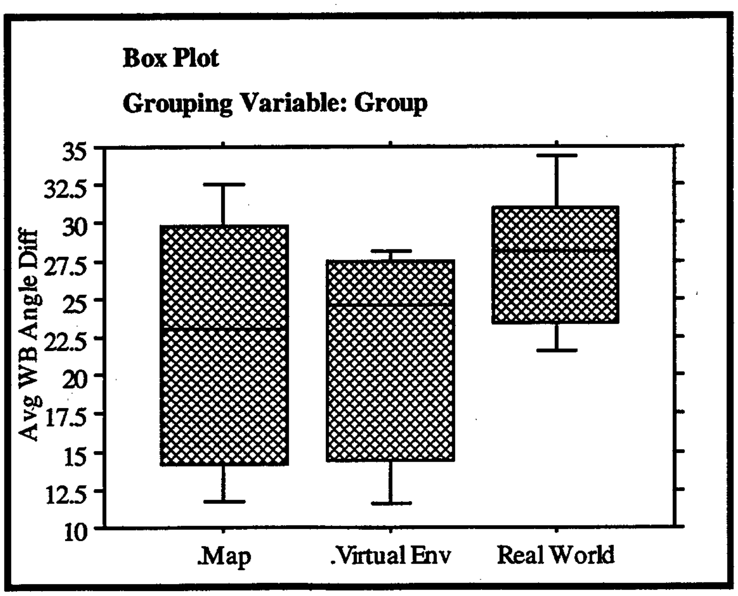


Figure 4.8. Interaction Box Plot for Average Whiteboard Angular Variance (Group)

Figure 4.8 displays the Average Whiteboard Angular Variances of all three treatments with a lower score indicating better performance. The means between groups are not statistically different, $\underline{F}(2,12) = 1.056$, $\underline{P} = .3781$. Direct observations indicate that on average, map and VE conditions had smaller average delta angle, approximately 21.5°, than the real world group, at roughly 27.5°. This indicates that the map and VE participants had a better exocentric reference than real world participants. The enhanced level of performance by the map group is due to continued exposure to the map. The VE participants' enhanced performance results from their exposure to the top down view with a "you are here" arrow. Because of these two aspects of the training phase, neither group had to worry about becoming lost in the environment. Real world participants had to rely on their navigation skills during the training phase to ensure they did not become disoriented. The effort required by real world participants to ensure they did not become lost reduced the time available to them to study the map and terrain. This resulted in their reduced level of excocentric knowledge of the environment.

c. Unplanned Route Execution

The unplanned route test was administered after the successful completion of the planned navigational task. The task consists of explaining the route the participant would take to reach Control Point 4 from Control Point 9 without referencing a map. The participant is then required to navigate to Control Point 4 from Control Point 9 without the use of a map or compass. Six of the participants completed their planned course and were administered the Unplanned Route Task. Of the six participants administered the task, only one navigated to Control Point 4 by a means other than the route used to reach Control Point 9 from Control Point 8. This was VE Participant Number 1 (Appendix O.6).

None of the participants tested committed an error enroute from Control Point 9 to Control Point 4. The average time to complete this task was five minutes and twenty-eight seconds. The data from the Unplanned Route Task is provided in Appendix O.6. For the participants who were administered the test, their performance indicates tendencies to travel previously visited terrain in order to link formerly unassociated controls. This supports the belief that landmarks are grouped and associated by common links even though they have never previously been closely coupled. Since only 40% of

the participants were administered this test, no conclusions can be draw between the effects of training tools on the performance of this task.

In conjunction with the Wheel Test and Whiteboard results, these figures indicate that the survey knowledge amongst all participants was not affected by the method of study. This could be a result of all participants having access to the same map from which to gain their survey knowledge. This coincides with Thorndyke's research [THOR 82] which showed that survey knowledge is gained through the study of external sources such as maps.

6. Navigational Performance by Training Condition

The results of the analysis indicate no statistical significance based on training condition. In general, direct observations suggest that map participants outperformed VE and real world participants. This can be the result of numerous factors including map fidelity, spatial ability, and route complexity.

A direct comparison of results is paradoxical because of the varying route complexities. In this experimental paradigm, participant performance on short difficult routes was compared to performance on longer easier routes. Problems encountered with identifying meaningful performance measurements, recording data, and conducting appropriate analysis were magnified since no two routes were identical. Providing each participant with a pre-planned route could have alleviated many issues. The result would have been an experiment testing the effect of the training conditions on route knowledge. Although interesting, a more important issue is how survey knowledge is affected by the different conditions. If VEs are to be a valuable navigational tool for the military, they must provide survey knowledge of the environment. Survey knowledge of an environment allows individuals to vary their routes based on current conditions and allows for more efficient movement through the environment. This is why participants must be allowed to explore the environment and plan their own routes.

B. DISCUSSION

1. Landmark Knowledge

To determine the participants' level of landmark knowledge, they were evaluated on their ability to locate and identify the control points. While executing the course, participants have three possible results on each leg: control point found, control point not

found, and time expired in route. Control point found indicates that the participant located and touched the appropriate control point. Participants receive full credit for locating the appropriate control point. An unfound control point is defined as a control point that participants could not locate because they were off their planned route and time had expired. A participant receives 33.33% credit towards a control found for attempting to locate the control point. If time expires while a participant is in route to the next control point, the participant is given 66.66% credit towards a control found for attempting to locate the control point. Participants are awarded this credit if they are enroute to the control point and on their preplanned route. The sum of these values is a participant's Landmark Knowledge Score (Appendix O.3).

Figure 4.9 displays the Landmark Knowledge Scores of all three conditions with a higher score indicating better performance. The means between groups are not statistically different, $F(2,12) = .563$, $P = .5840$ (Figure 4.1). Direct observation suggests that on average, map and real world participants located more controls than VE participants. This cursory analysis of the data does not indicate whether the participants

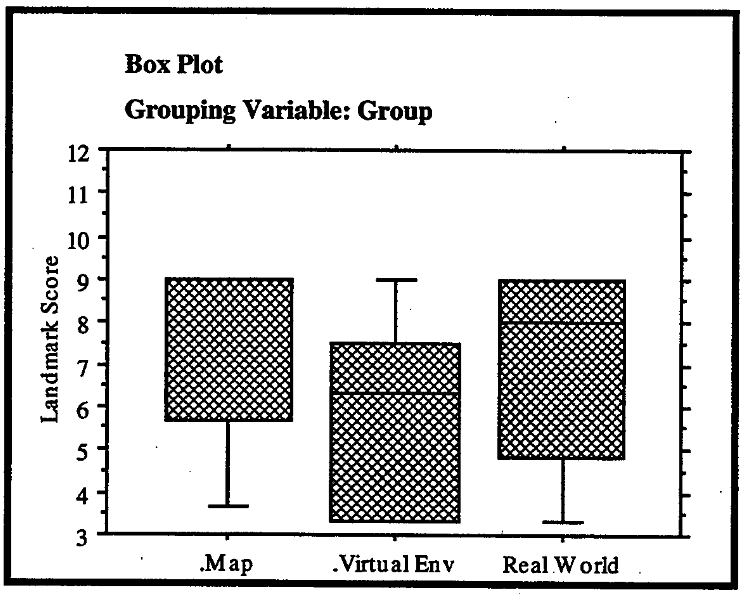


Figure 4.9. Interaction Box Plot for Landmark Knowledge Score

were having the majority of their problems during coarse movement through the environment (Appendix Q) or while searching for the control in the general location of the objective. A better measurement of landmark knowledge would have been to

measure the time or distance traversed as a participant searched within the general area of the control (25m).

2. Route Complexity by Training Condition

Figure 4.10 displays the ISOM Average Planned Route Complexities Scores of all three treatments with a lower score indicating an easier route. The VE condition planned less aggressive routes than the other two with a mean route complexity of roughly 1.5. The map condition followed closely with a mean route complexity of approximately 1.75 and real world conditions trailed with 2.0. The means between groups are not statistically different, $F(2,12) = 1.247$, $P = .3222$. Direct observations indicate that on average,

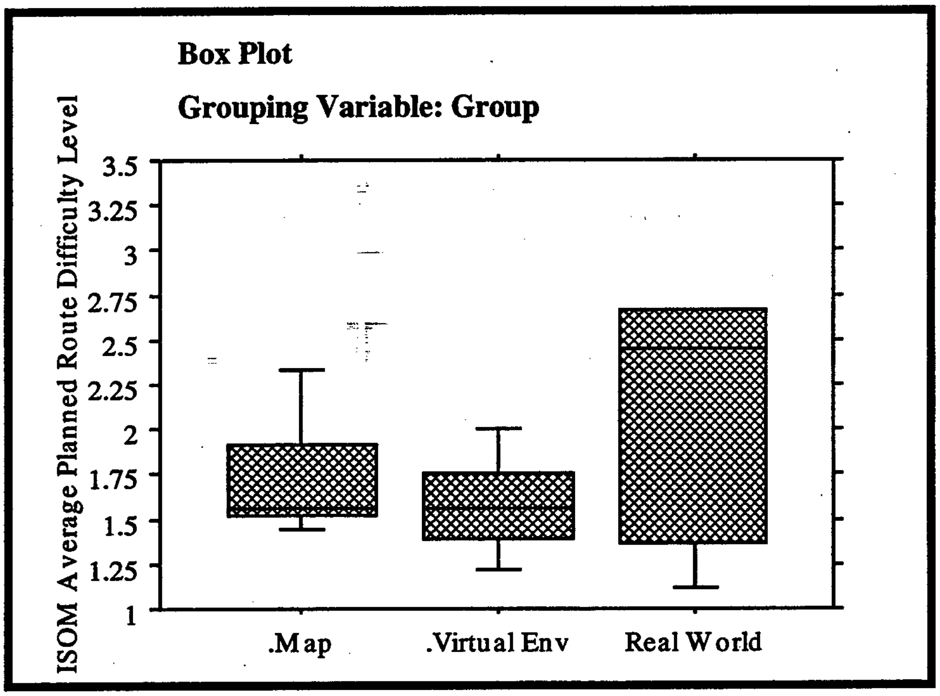


Figure 4.10. Interaction Box Plot for ISOM Average Planned Route Complexity (Group)

participants in the VE group tended to plan less complex routes. This indicates that the VE provided participants with information concerning the complexity of the environment which they could not gain from the map or failed to gain from the real world. Time compressed training allowed VE participants to explore more of the terrain than the real world participants were able to traverse during the training phase. This afforded VE participants the opportunity to plan less complex routes by taking advantage of the information gained from the VE. Map participants did not have the opportunity to

translate their propositional knowledge gained of the environment into imagery. This may have prevented them from identify more simplistic routes through the course.

3. Wheel Test Results Visited vs Unvisited Control Points

a. Visited vs Unvisited Control Points

A post-hoc analysis was conducted on the average angular differences between previously visited and unvisited control points on the Wheel Test. The analysis was done to see if participants had better conceptual placement of controls visited vs controls not yet visited indicating a better egocentric conception of visited controls.

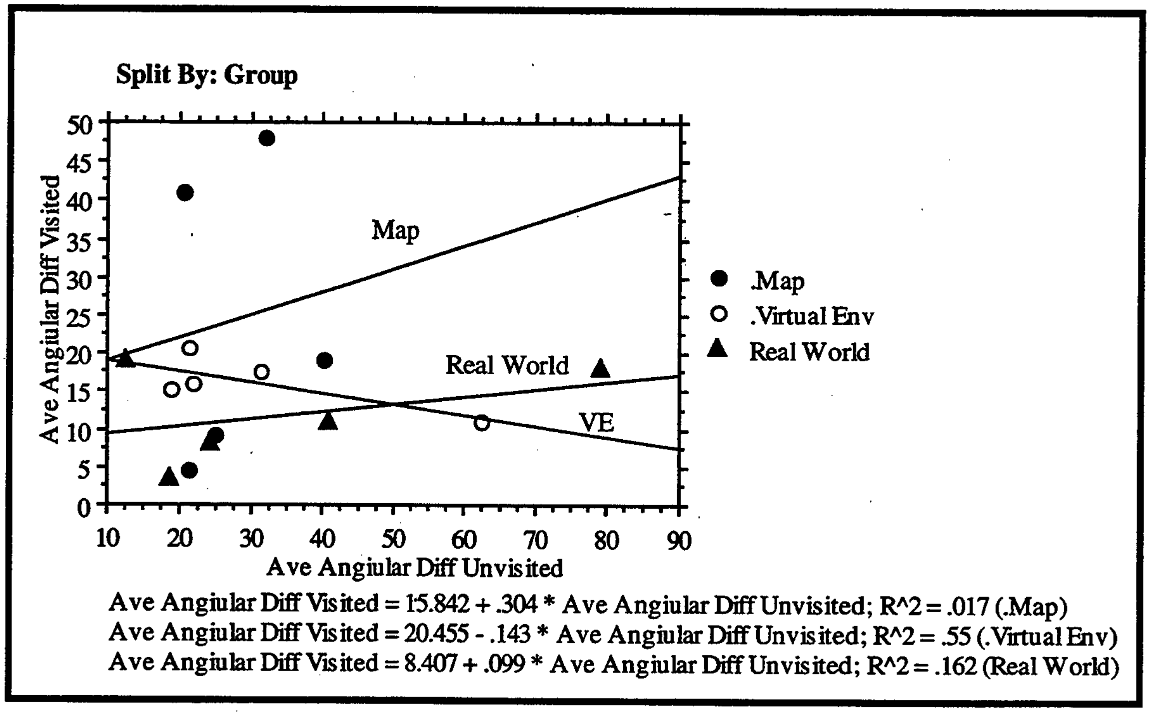


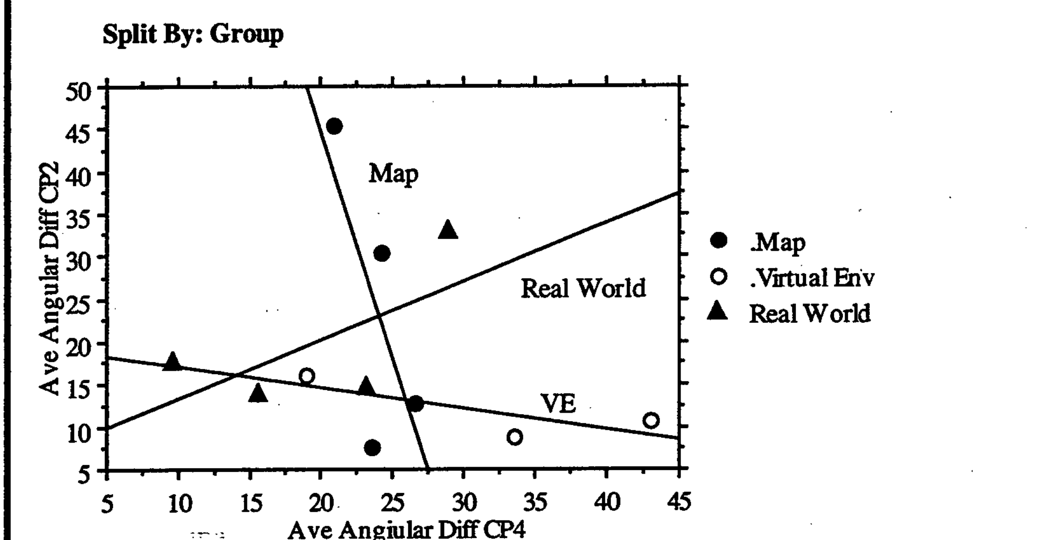
Figure 4.11. Scattergram for Wheel Tests Results by Controls Visited and Unvisited

A line with a slope of one would indicate similar angular difference between controls visited and controls not visited. Horizontal regression lines suggest that performance on visited controls was better than those for unvisited controls. Figure 4.11 exhibits nearly horizontal regression lines for all three groups. This indicates that participants had better spatial placement of visited controls than unvisited controls. Map participants showed scatted results suggesting that placement of controls in each individual's mental representation of the world varied based on how they grouped the controls. Further research is needed to verify these suggested results and to determine if

objects further along on the course are more difficult to place within the mental representation than objects closer on the route.

b. Control Point 2 vs Control Point 4

Additional post-hoc analysis was performed to determine if participant performance improved or degraded on the Wheel Test conducted at CP4 compared to the test at CP2. The comparison is meant to determine if individual performance improves the longer that the participant is exposed to the actual environment. The inference is that increased exposure time allows individuals to resolve the differences between their mental maps and the actual terrain.



Ave Angular Diff CP2 = 151.159 - 5.317 * Ave Angiular Diff CP4 ; R^2 = .518 (.Map)
Ave Angular Diff CP2 = 19.652 - .247 * Ave Angiular Diff CP4 ; R^2 = .621 (.Virtual Env)
Ave Angular Diff CP2 = 6.46 + .689 * Ave Angiular Diff CP4 ; R^2 = .43 (Real World)

Figure 4.12. Scattergram for Wheel Tests Results by Test Location

Only participants who performed the Wheel Test at both locations were used in this comparison. Although no conclusions can be drawn from the results, observations of the research personnel suggest that on average, Figure 4.12 shows assorted results depending on the group. Map participants had mixed results for average wheel test scores at Control Point 2. They showed a clustering of results around the 25° variance measurement for their scores at Control Point 4. This produces in a nearly vertical regression line indicating improved and standardized results at Control Point 4 with assorted results at Control Point 2.

The VE group results produce an approximate horizontal regression line. This denotes a clustering of results around the 15° mark for their scores at Control Point 2 while exhibiting more dispersed results At Control Point 4. This suggests diminishing performance for the VE participants between the two test sites. Real world participant data resulted in a positively sloped regression line that suggests that the average performance of individuals remained relatively constant between the two testing sites. Overall results suggest that increased exposure to the environment had little effect on performance of participants egocentric representation of the environment.

4. Spatial Ability Post-Hoc Correlation

To assist in determining additional tests that may predict individual navigational performance, individual post-hoc ANOVAs were run with the independent variables being the Self Evaluation Bar Test, the Santa Barbara Sense-of-Direction Scale, the Map Reading Test, and the GZ Test. The dependent variables were the same as those used for analyzing navigational performance (Chapter 4.A.5). No significance was shown when running the dependent variables against the independent variables Self Evaluation Bar Test, Santa Barbara Sense-of-Direction Scale, and Map Reading Test. Potential statistical significance exists with regards to the independent variable GZ Ability Groups. Only the analysis of the GZ Ability Group results will be discussed. All dependent variables analyzed use the same criteria utilized in the factorial analysis of the dependent variables by the independent variable group (Chapter IV, Sections A.4 & A.5).

a. Route Knowledge

1) Errors

Figure 4.13 displays the Errors Per Control Attempted based on the two Guilford-Zimmerman conditions with a lower score indicating better performance. The results do not display statistical significance between the two groups, $\underline{F}(1,12) = 4.040$, $\underline{P} = .0656$. Direct observations indicate that on average, participants who scored higher on the Guilford-Zimmerman Test committed fewer errors than those who scored lower. This suggests that individuals with higher GZ scores are better able to follow their planned routes. This could be due to route selection, organization of mental map, or memory skills. Further research is needed to determine what factors the GZ score influences and what impact these variables have on navigational ability.

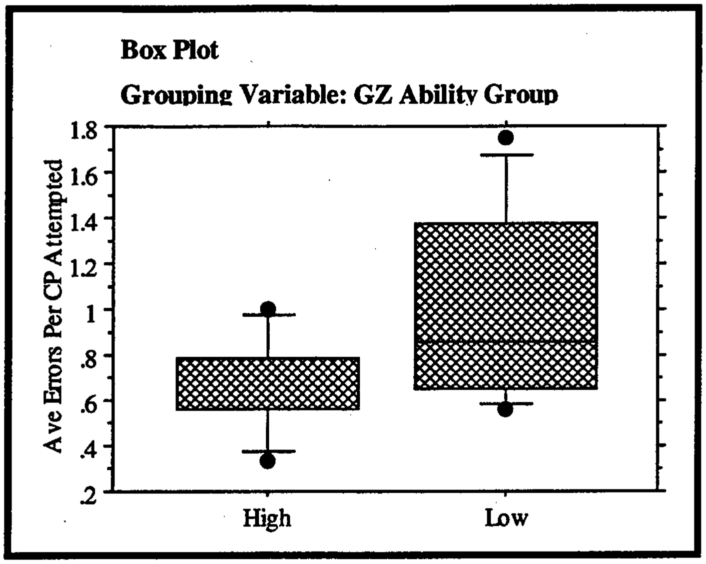


Figure 4.13. Interaction Box Plot for Errors Per Control Attempted (GZ)

2) Distance Traveled Per Error

The Normalized Average Distance Per Error of the two conditions is shown in Figure 4.14 with lower score indicating better performance. The groups show statistical significance, $\underline{F}(1,13) = 9.702$, $\underline{P} = .0082$. Participants who scored higher on the Guilford-Zimmerman Test traveled shorter distances per error. This implies that individuals with higher GZ scores identify their errors and can recover from them faster than those individuals who have lower GZ scores. Since participants with higher GZ scores

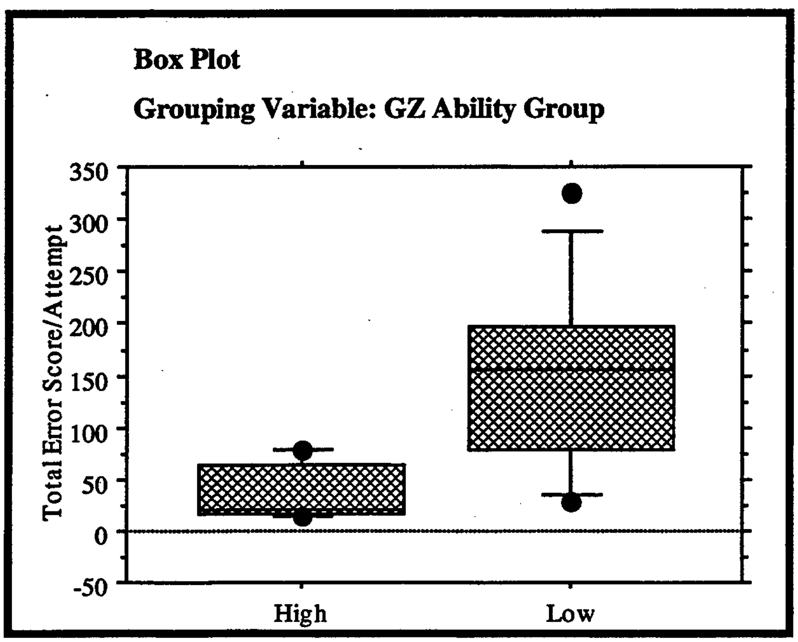


Figure 4.14. Interaction Box Plot for Normalized Average Distance Per Error (GZ)

committed fewer errors and recovered from them faster than participants with lower GZ scores, they were also able to attempt more control points. This helped to improve their self-confidence as they continued on the course and reduce their scores that were normalized by controls attempted. This provides credence to and justification for the observation that they were able to obtain better route knowledge of the environment than the average participant with a lower GZ score.

3) Map and Compass Checks

Figure 4.15 displays the Normalized Map Scores based on the two Guilford-Zimmerman conditions with a lower score indicating better performance. The results failed to show statistical significance between the two groups, $\underline{F}(1,13) = 4.254$, $\underline{P} = .0597$.

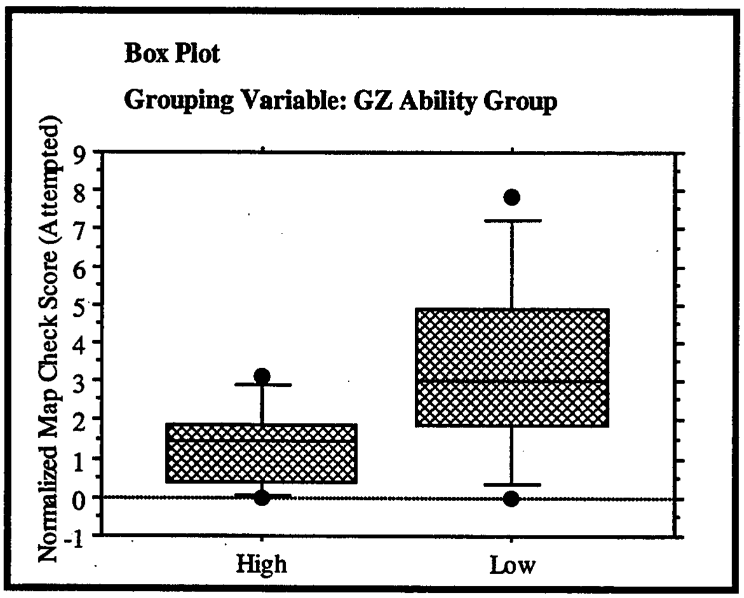


Figure 4.15. Interaction Box Plot for Normalized Map Score (GZ)

Although no conclusions can be drawn from the results, direct observation suggest that on average, participants who scored higher on the Guilford-Zimmerman Test required fewer checks and corrections by monitors than those who had lower GZ scores. This implies that individuals with higher GZ scores had more confidence in their memory and mental maps than individuals with lower GZ scores. This is a result of their spatial ability which allowed them to organize a specific set of navigation cues or develop an accurate mental map. These skills also allowed them to confirm or modify their mental representations as they were presented with conflicting information during execution of the course (Appendix Q).

b. Survey Knowledge

1) Wheel Test

The Normalized Average Distance Per Errors of the two conditions with a smaller deviation indicating better performance is shown in Figure 4.16. The means between groups shows a statistical difference, $\underline{F}(1,13) = 6.064$, $\underline{P} = .0285$. Direct observations of the research personnel suggest that on average, participants who scored higher on the Guilford-Zimmerman Test had smaller average delta angles indicating they had a better exocentric reference than lower GZ score participants. This is a result of their enhanced ability to fix their position in their mental representations and then rotate their mental maps to identify the relative position of the control points based on their location.

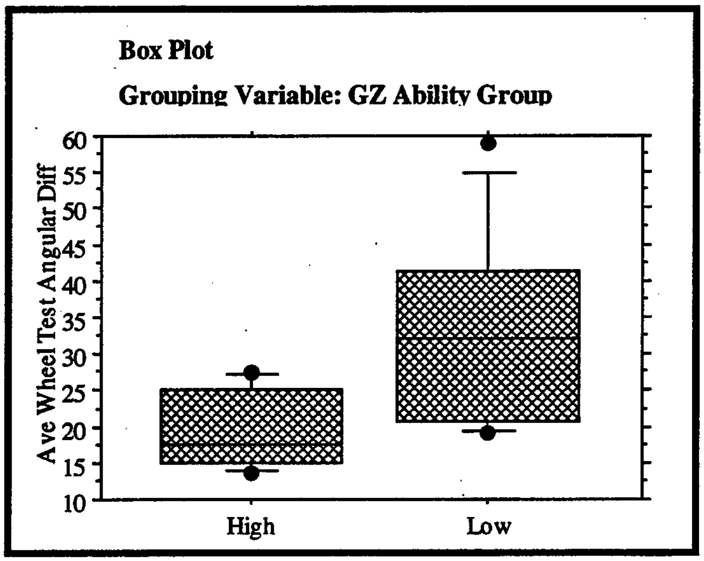


Figure 4.16. Interaction Box Plot for Average Wheel Test Angular Variance (GZ)

2) Whiteboard Test

Figure 4.17 displays the Average Whiteboard Angular Variances based on the two Guilford-Zimmerman conditions with a smaller deviation indicating better performance. The results failed to show statistical difference between the two groups, $\underline{F}(1,13) = .128$, $\underline{P} = .7258$. Direct observations of the research personnel suggest that on average, the Guilford-Zimmerman Test results had no impact on the average delta angles indicating both higher and lower scoring individuals have similar abilities to acquire valid exocentric representations of the environment. Since this test did not require participants

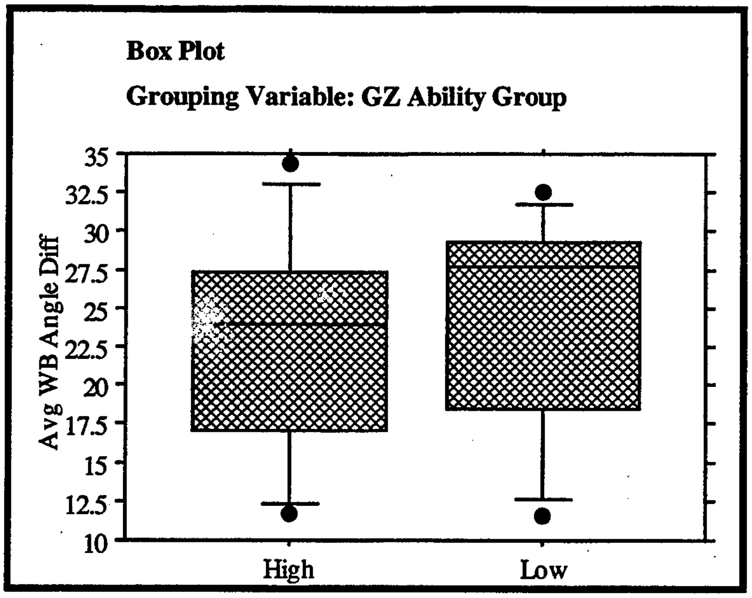


Figure 4.17. Interaction Box Plot for Average Whiteboard Angular Variance (GZ)

to conduct a mental rotation of the environment, spatial ability did not have the same affect on performance as it did on the wheel test (Chapter IV, Section B.4.b.1). This indicates that excocentric spatial knowledge is independent of egocentric spatial knowledge with regards to spatial ability. As a result, survey knowledge must be evaluated based on both excocentric and egocentric measures.

3) Unplanned Route Execution

The Normalized Average Distance Per Errors of the two conditions is shown in Figure 4.18 with lower score indicating better performance. The means between groups indicates statistical difference, $\underline{F}(1,13) = 7.316$, $\underline{P} = .0180$. Direct observation suggests

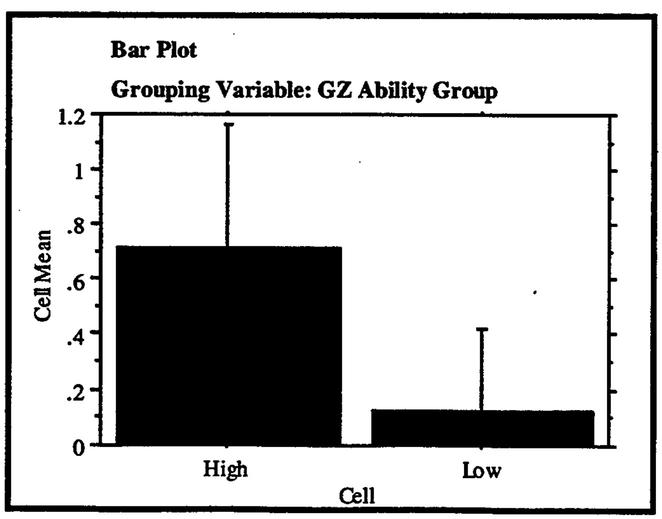


Figure 4.18. Interaction Bar Plot for Unplanned Route Execution (GZ)

that on average, a participant who scored higher on the Guilford-Zimmerman Test was more likely to complete the course in time and be administered the unplanned route task. Since participants with higher GZ scores were more likely to complete the course, it is more likely they had acquired the survey knowledge required to perform the unplanned route task than those individuals who had lower GZ scores. This implies that individuals with higher GZ scores have the ability to obtain overall route and survey knowledge faster than those individuals who have lower GZ scores.

c. *Route Complexity by Spatial Ability*

1) Route Planning

Figure 4.14 displays the ISOM Average Planned Route Complexities based on the two Guilford-Zimmerman conditions with a lower score indicating easier route. The results suggest statistical significance between the two groups, $\underline{F}(1,13) = 8.614$, $\underline{P} = .0116$. Direct observations indicate that on average, participants who scored higher

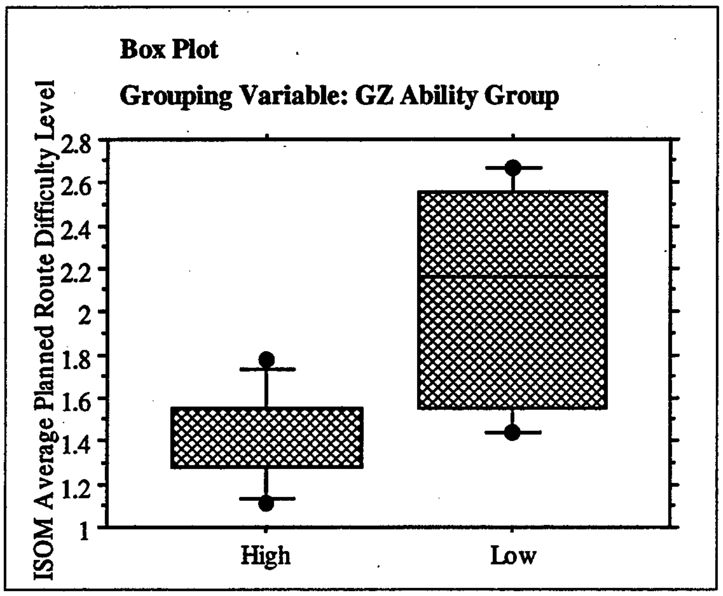


Figure 4.19. Interaction Box Plot for ISOM Average Planned Route Complexity (GZ)

on the Guilford-Zimmerman Test planned less difficult routes (1.417, high beginner) than those who scored lower (2.422, high intermediate). This implies that those individuals with higher GZ scores are better able to identify simple routes through this environment.

The ability of higher GZ score participants to identify and plan more simplistic routes is the result of their ability to conduct mental rotations of the map symbols or environmental imagery. This allowed them to mentally visualize decision points

throughout the environment and determine which features would provide the best directional, identification, and reassurance signs (Appendix Q). These signs helped them to confirm their position and orientation along their planned route prior to executing the course.

2) Route Planning vs Average Error Score

Figure 4.20 displays the ISOM Average Planned Route Complexities based on the two Guilford-Zimmerman conditions and Normalized Average Distance Per Error with a score in the lower left corner indicating easier route and better performance. The results do not indicate statistical significance between the two groups, $\underline{F}(2,14) = 3.710$, $\underline{P} = .0557$. Direct observations indicate that participants who scored higher on the

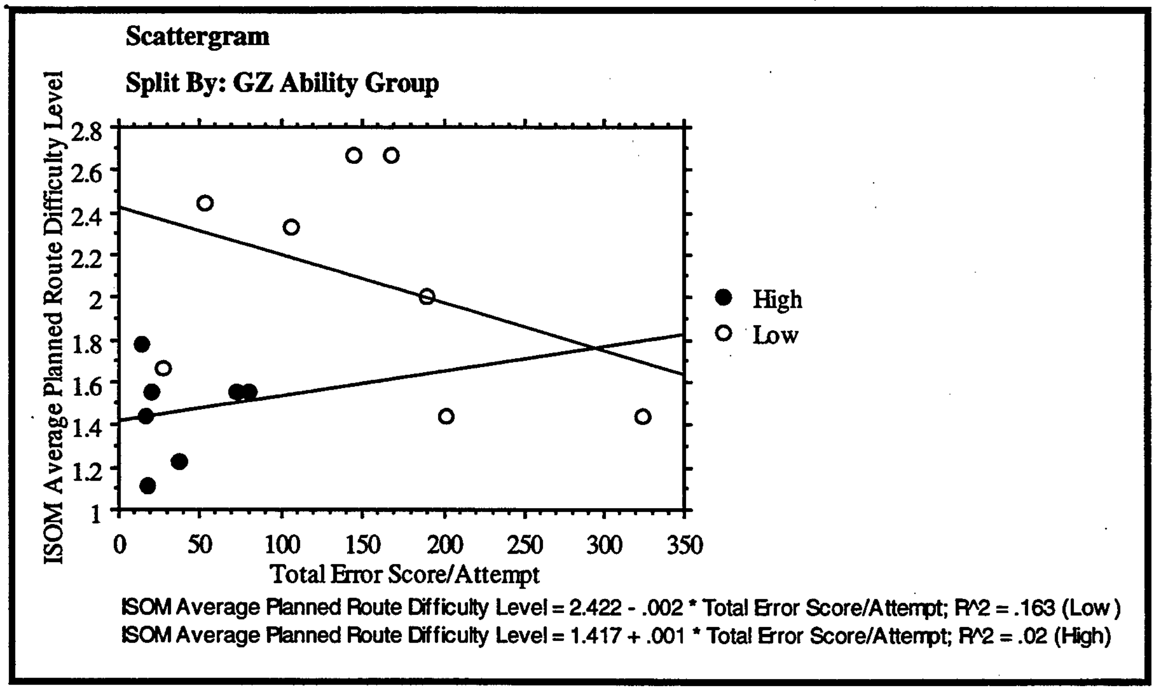


Figure 4.20. Scattergram for ISOM Average Planned Route Complexities (GZ)

Guilford-Zimmerman Test planned less difficult routes and were able to follow those routes better than those who scored lower. This implies that individuals with higher GZ scores are better able to plan routes that allow them to identify when they have left their routes. This allows them to quickly recover from their errors and continue on the planned route.

d. *Navigational Performance by Spatial Ability*

The results of the analysis of route and survey knowledge based on spatial ability suggest possible statistical significance. This implies that spatial aptitude has a more profound impact on navigational performance than training effect. This could be due to the individuals' ability to understand the complexity of the task, plan a more appropriate route, and resolve differences in their mental maps while executing their planned routes. The data does not imply that lower scoring GZ participants could not execute their planned route. Instead it suggests that they did not understand the complexity of the task and planned routes which were too complex to execute within the allotted time.

5. Debriefing Questionnaire

To provide a qualitative analysis of the tools and course used for the experiment, participants were given a debriefing questionnaire. The map and real world groups' version of the questionnaire (Appendix E.8) did not have any questions concerning the experiment model or its interface. The VE group questionnaire asked specific questions regarding the experimental model and interface. A five-point scale (1-5) was used for the questionnaire.

a. *Map Questions*

Qualitative analysis of the map indicates that map participants had more confidence in the 1:5,000 orienteering map than their real world or VE counterparts (Questions MapQ2 – MapQ6). This is partially due to the need for real world and VE participants to resolve differences in the mental maps they created during the training phase and the course they were running for the execution phase (Chapter IV, Section B.11). Real world and VE participants showed less confidence in the map's ability to depict vegetation even though the experiment map used the more descriptive depictions of orienteering maps than the traditional military representations. The mean qualitative score was 3.4, adequate representation, and scores ranged from 1 to 5. The participants felt the map allowed them to easily plan their routes (Question MapQ7). This indicates that the map was a useful tool for all participants.

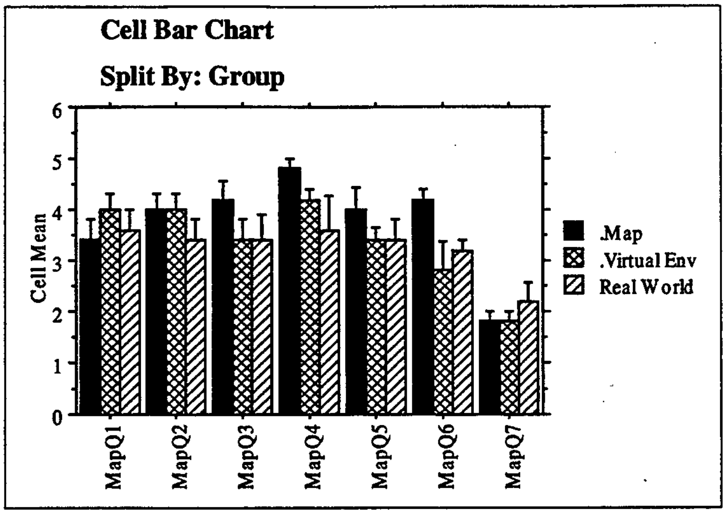


Figure 4.21. Cell Bar Chart for Debriefing Questionnaire (Map Questions)

Code	*Question*
MapQ1	Was the map easy to read?
MapQ2	Was the map easy to understand?
MapQ3	Were the trails & roads adequately shown on the map?
MapQ4	Were the man-made structures adequately shown on the map?
MapQ5	Were the obstacles adequately shown on the map?
MapQ6	Was the vegetation adequately shown on the map?
MapQ7	Using the map, how difficult was it to plan your route?

Table 4.1. Map Questions

b. Course Questions

Qualitative analysis of the course indicates that map participants felt the course was moderately difficult and that control points were well marked and located in the general location they had expected them (Questions CourseQ1 – CourseQ3). On average, participants felt that trails had been trampled down between controls with scores ranged from 1 – 4 (Question CourseQ4). This did not help participants locate CP2 or CP4. Trails only provided confidence when participants were on their desired route. The trails created confusion when participants were disoriented. The reported difficulty of remembering one's planned route ranged from easy to hard with a mean value of 3.667 indicating that the average participant found this to be moderately difficult (Question CourseQ5). Virtual environment participants felt they were better able to remember their planned routes than did the map or real world participants.

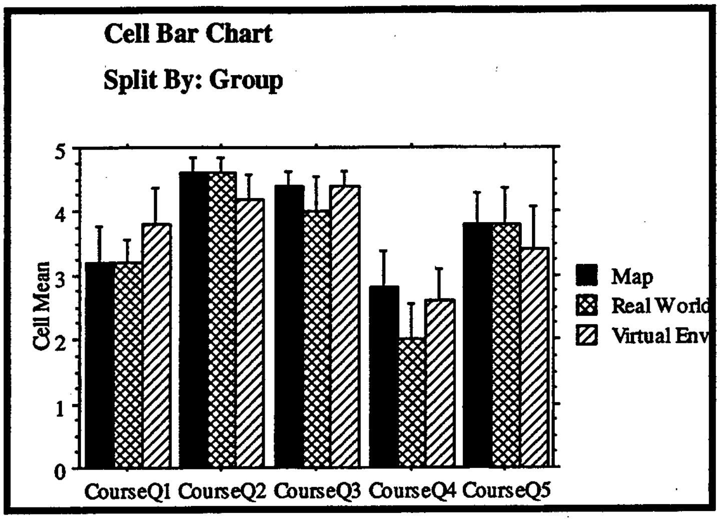


Figure 4.22. Cell Bar Chart for Debriefing Questionnaire (Course Questions)

Code	Question
CourseQ1	How difficult was the course?
CourseQ2	Were the control points well marked?
CourseQ3	Were the control points located where you expected them?
CourseQ4	Had routes been trampled down leading to the control points?
CourseQ5	Did you have difficulties remembering your planned route?

Table 4.2. Course Questions

c. *Miscellaneous Questions*

Map participants felt they had sufficient time to plan and study their routes (Questions MiscellaneousQ2 and MiscellaneousQ3). Virtual environment and real world participants felt they could have used more time. Resolving differences in the environment requires time and exposure to the terrain (Chapter IV, Section B.11). The reasons for this are similar to the rationale behind why participants in the VE and real world groups were less confidant in the map (Chapter IV, Section B.4.a). The time used to resolve these issues distracts from the time allotted to plan and practice a route through the environment.

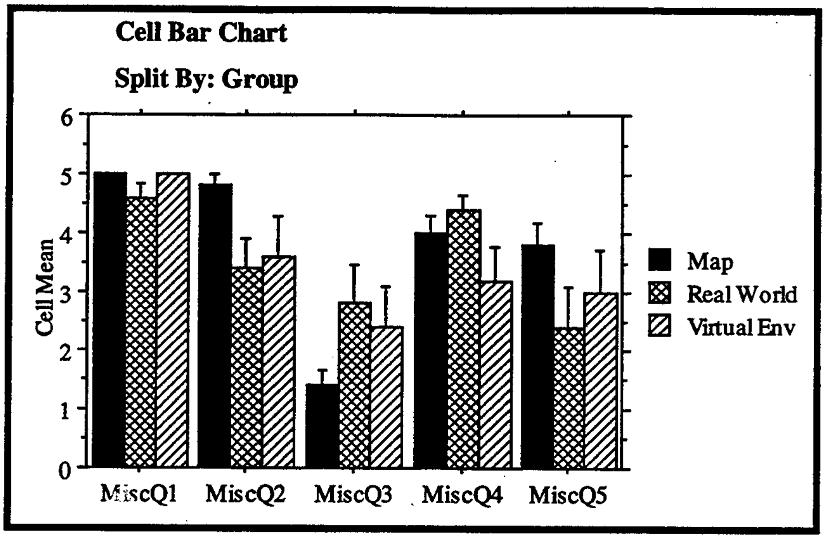


Figure 4.23. Cell Bar Chart for Debriefing Questionnaire (Miscellaneous Questions)

Code	*Question*
MiscQ1	Did you enjoy this experiment?
MiscQ2	Did you feel the training phase was long enough?
MiscQ3	Did you feel the training phase was too short?
MiscQ4	Do you feel the training familiarized you learn the environment?
MiscQ5	Did you feel confident in navigating the terrain without a map or compass?

Table 4.3. Miscellaneous Questions

Map participants felt more confident in navigating through the environment without the use of the map (Question MiscellaneousQ5). Real world participants felt less confident than their map and VE counterparts. This is due to the real world participants' inability to explore the entire environment during the training phase. Four of the five real world participants failed to make it past Control Point 6 during the study phase. These participants were unsure of the environment on the south side of the course. The southern half of the course was depicted as having more undergrowth and greater changes in elevation than the northern half of the course (Appendix F.6). This limited exposure to the environment translated into a lack of confidence in navigating without the use of the map.

d. Model Questions

Map participants felt the model correlated well with the map and was easily viewable (Questions ModelQ2 and ModelQ1). Participants felt that the elevation representation and man-made structures were well represented in the model (Questions ModelQ7 and ModelQ4). These elements of the model assisted participants with

identifying the general area in which they would locate the controls and enhanced their confidence in the training they had received (Questions ModelQ9 and ModelQ11).

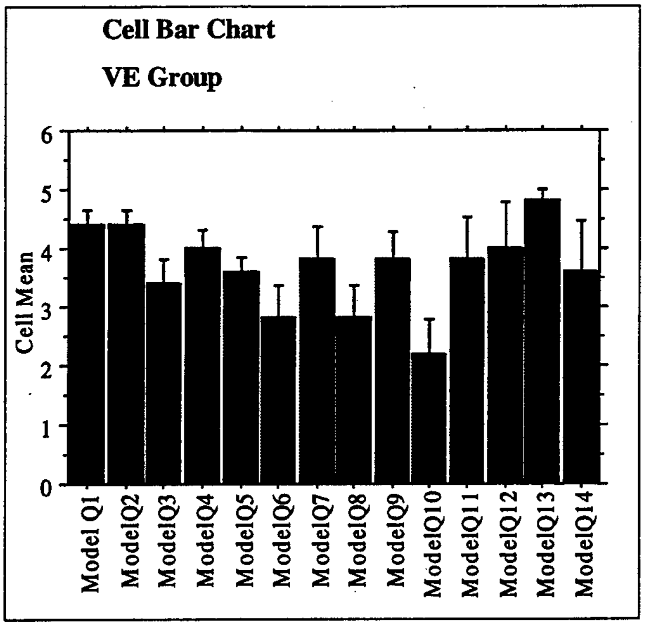


Figure 4.24. Cell Bar Chart for Debriefing Questionnaire (Model Questions)

Code	*Question*
ModelQ1	Was the model clear and viewable?
ModelQ2	Did the model coincide with the map?
ModelQ3	Were the trails & roads adequately represented in the model?
ModelQ4	Were the man-made structures adequately represented in the model?
ModelQ5	Were the obstacles adequately represented in the model?
ModelQ6	Was the vegetation adequately represented in the model?
ModelQ7	Were changes in elevation adequately represented in the model?
ModelQ8	Did the model help you identify the control points within the last 50m?
ModelQ9	Did the model help you identify the general area of the control points?
ModelQ10	Using the model, how difficult was it to plan your route?
ModelQ11	Do you feel the model gave you an advantage you normally wouldn't have had?
ModelQ12	Would you use this tool if it were available for mission planning?
ModelQ13	Would you use this tool if it were available for mission rehearsal?
ModelQ14	Would you use this tool if it were available for navigation training?

Table 4.4. Model Questions

Participants had only moderate confidence in the trail network, obstacles, and vegetation representations in the model (Questions ModelQ3, ModelQ5, and ModelQ6). This lead to participants having difficulty in identifying the controls once they were within 50m of the control (Question ModelQ8) during the execution phase. This is due to the low-level vegetation (grass and brush) and smaller depressions of the actual course

that were not as detailed in the model. This is more apparent for controls located at ground level, Control Point 2 and Control Point 4, where more errors were made attempting to locate these controls than any of the other controls (Chapter IV, Section B.7).

Participants were more likely to use the model for mission rehearsal (Question ModelQ13) than for mission planning or training of general navigation skills (Questions ModelQ12 and ModelQ13). Participants felt the model provided moderate assistance in planning their routes (Question ModelQ11). It is interesting to note that even though their overall navigation performance was not as good as the map only participants, the VE participants had enough confidence in the model to use it for mission rehearsals.

e. *Interface Questions*

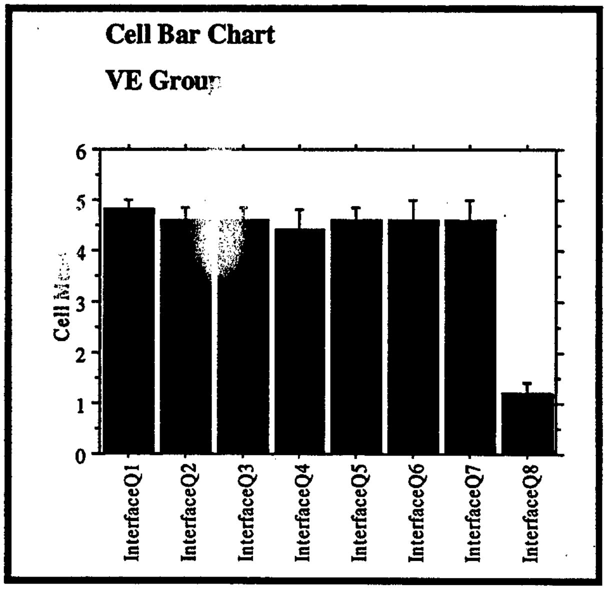


Figure 4.25. Cell Bar Chart for Debriefing Questionnaire (Interface Questions)

Code	*Question*
InterfaceQ1	Were you able to easily move through the model?
InterfaceQ2	Was the joystick easy to use?
InterfaceQ3	Was the acceleration lever easy to use?
InterfaceQ4	Were the toggle buttons easy to use?
InterfaceQ5	Your overall felling about the interface?
InterfaceQ6	Was the 15-minute train-up on the initial model useful?
InterfaceQ7	Was the 15-minute train-up on the initial model enough time to become familiar with the interface?
InterfaceQ8	Did the use of three screens cause any confusion when maneuvering?

Table 4.5. Interface Questions

As expected from their relative ease in moving through the environment and the limited tasks which the participant was asked to perform in the model, VE participants felt the model interface was user friendly (Questions InterfaceQ1 – InterfaceQ7). Also, the three-screen configuration provided them with no difficulties in viewing the environment (Question InterfaceQ8).

f. Model Needs

The last page of the questionnaire asked participants to list the items they felt would best assist them in navigating through a VE and real world. Streams and rivers were deliberately left off the list of possible water features to see if participants would pick these as linear features that should be portrayed in a VE. Findings are discussed by object groupings: buildings, miscellaneous objects, obstacles, roads, terrain, vegetation, and water.

1) Buildings

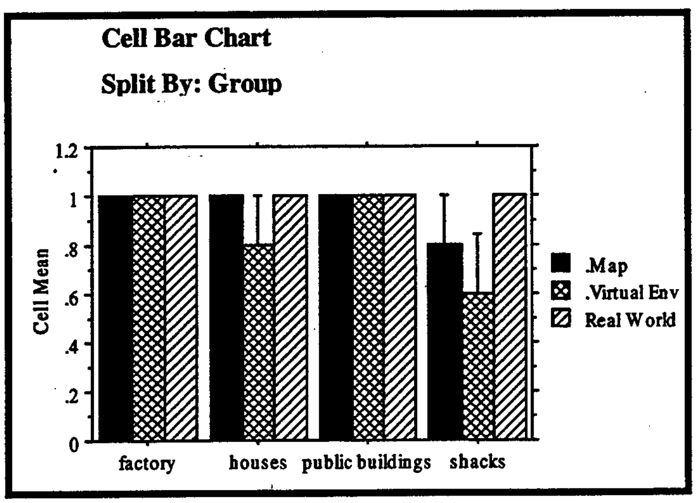


Figure 4.26. Cell Bar Chart for Model Needs (Buildings)

Virtual environment participants were more discerning in the types of buildings that they wanted displayed in a model. They differentiated between more permanent and distinguishable buildings such as factories and public structures (churches, fire stations, schools, and government buildings) and the more abundant and ever changing structure of houses and shacks. This demonstrates the ability of VE participants to identify the more prominent landmarks in the model and disregard the less distinctive objects.

2) Miscellaneous Objects

Nearly all the participants sought assistance from directional aids. A compass or virtual sun that can provide cues to direction of travel were the most requested items in this category. Map participants would also like to have location indicators such as street and road signs. Virtual environment participants viewed complex items such as rock piles as being useful. This is due to the perception that if a model builder is going to put forth the effort to represent such a complex object, it must be a valid landmark.

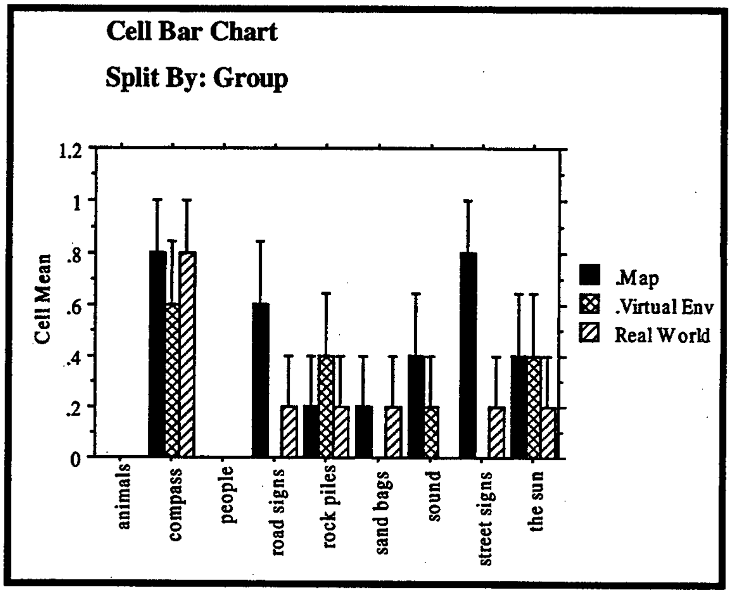


Figure 4.27. Cell Bar Chart for Model Needs (Miscellaneous Objects)

All participants agreed that a model whose purpose is to provide spatial knowledge of an environment does not need to represent movable entities such as people and animals. Sound is also not seen as an essential need for most participants. This is due to the fact that moving entities and sounds provide little directional cues to the model user. The exception to this is the sound of a stream or highway noises. If these items can be spatially represented in the VE, they can provide navigational cues to the user. On weekends when training was being conducted at the Fort Ord Military Operations Urban Terrain (MOUT) Site, participants could maintain cardinal directions based on the sounds of weapons located southeast of the orienteering course. Sound based navigation cues were also provided by motorcycle or Formula One engines when races were held at the Laguna Seca Raceway which is also located southeast of the orienteering course.

3) Obstacles

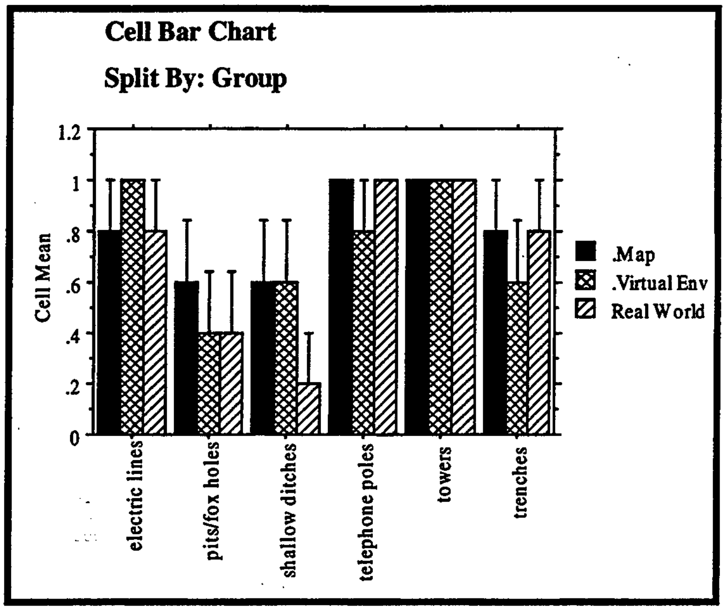


Figure 4.28. Cell Bar Chart for Model Needs (Obstacles)

Objects that are easily viewable from a distance or present a major impact on mobility are highly requested in a VE. Participants requested vertical obstacles and elevated obstacles more often then smaller, more easily bypassed obstacles such as pits and shallow ditches. This is because the vertical and elevated obstacles are more permanent due to the difficulty to construct in the real world and because they can be easily seen and used as navigational aids.

4) Roads

Participants desire the representation of more permanent man-made linear landmarks such as roads. They are less prone to changes and provide a rapid means of travel through the environment. Roads also link more prominent landmarks which participants use for coarse movement (Appendix Q) through the environment. Trails also provide valuable information but, are more subject to change and are therefore less reliable. Footpaths change with the seasons and can be easily produced by man or animal and are less direct in their course through the environment. Footpaths may not lead participants to their intended destination which leads to a general distrust of paths that have not been traveled previously by the participant.

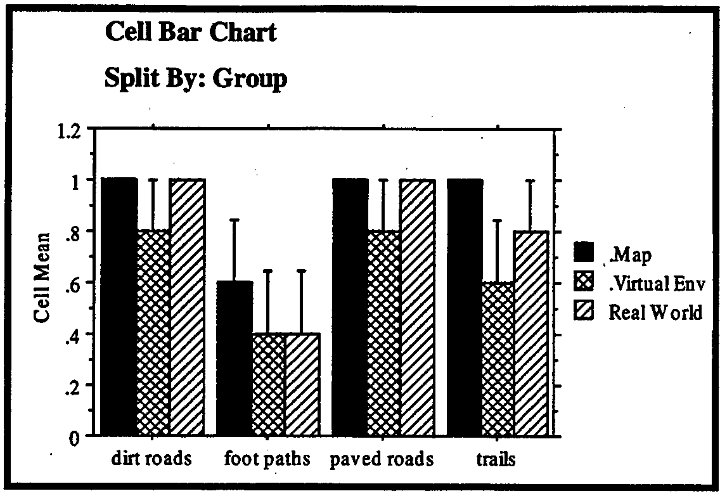


Figure 4.29. Cell Bar Chart for Model Needs (Roads)

5) Terrain

Terrain elevation plays a major part in determining one's location in an environment. Participants desire adequate representation in changes of elevation. Terrain which is easily viewable from a distance (hills and ridgelines) was most often requested. A contradiction to this is the desire for spurs and fingers to be adequately represented but, not their compliment, draws. The two are distinguishable at a distance but, a lack of terrain elevation is not seen as important to the participants as the presence of elevated terrain. This is likely a result of no draws being present in the testing environment.

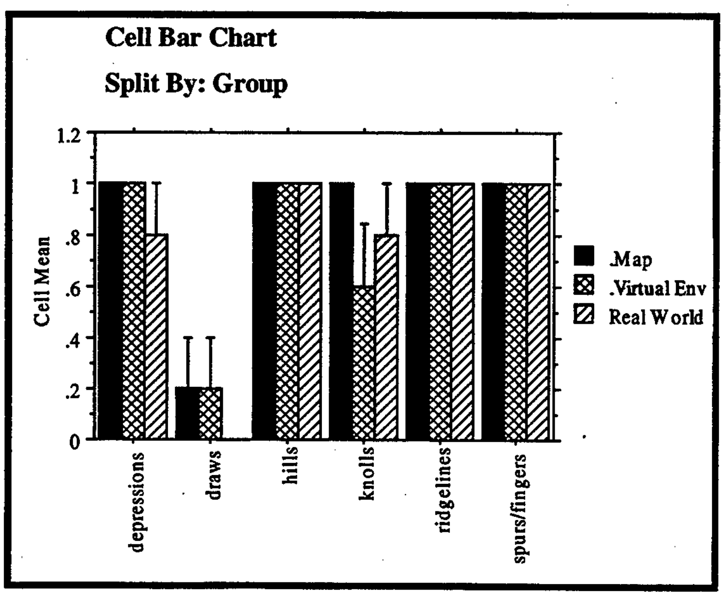


Figure 4.30. Cell Bar Chart for Model Needs (Terrain)

One of the major problem locations on the course was Control Point 4 which was located in a depression. Because of the difficulty many participants had with this control, many of them indicated the need for depressions to be adequately represented in a VE used to provide spatial knowledge of an environment. If a control point was located in a draw, more participants would have identified this as a type of terrain which must be adequately represented in the model.

6) Vegetation

Participants identified a lack of vegetation (a clearing) as a vital element of a VE. Participants understood that no matter how accurate the placement of vegetation in the environment, most of the trees and bushes are randomly placed and therefore should not be used as landmarks. Clearings, or the lack of vegetation, is seen as a more defining characteristic of a wooded environment, much as an oasis in a desert. It is the differences in vegetation which make the area distinguishable from its surroundings and useful in determining one's location.

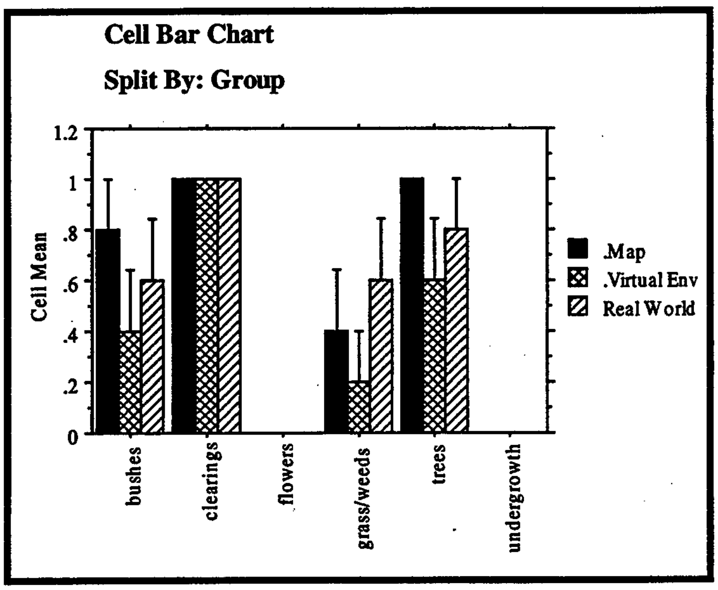


Figure 4.31. Cell Bar Chart for Model Needs (Vegetation)

Undergrowth and flowers are seen as unnecessary fillers. This is in direct contradiction to the responses of the VE participants who felt the lack of grass and undergrowth in the model made it more difficult to locate controls placed at ground level (Chapter IV, Section B.4.d). This does indicate that VE participants realize that these items are not necessary for general navigation through an environment. Although

undergrowth may hinder cross-country movement, it provides little interference with visibility at elevations greater than three feet above the model's surface.

Since trees and brush do hinder visibility and movement through the environment, participants see a need for them to be represented in the environment. This type of vegetation provides an indication on which routes provide cover and concealment and which routes may make rapid cross-country movement impossible.

7) Water

Participants desire the representation of major bodies of water in the VE. The reasons are similar to those used for determining the types of roads and trails they would like represented (Chapter IV, Section B.4.f.4). Major bodies of water change relatively little compared to creeks and puddles that may be here one day and gone the next.

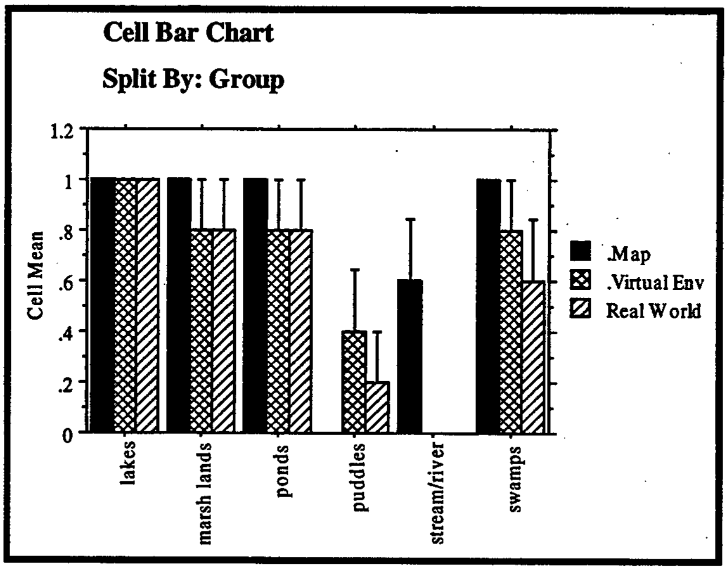


Figure 4.32. Cell Bar Chart for Model Needs (Water)

Streams and rivers were not on the list of water objects provided to the participants (Appendix E.8). Two map participants added these to their list of objects that should be represented. Streams and rivers can provide the same types of navigational cues as paved and dirt roads; however, they are susceptible to course changes due to increased precipitation levels and soil erosion.

8) General Comments

Map participants showed a greater desire for information than the VE and real world participants. They requested more objects be portrayed in the VE than the other

two groups. This indicates that VE and real world participants may have a better understanding of what landmark and defining terrain features are best used to navigate through the virtual world and can be easily identified during movement through the actual terrain.

Although streams, rivers, and bridges were left off the list of potential model objects, they should be included in a virtual model. By their nature, they define boundaries within the environment and passageways between those boundaries. Although dismounted and mounted forces may be able to ford water obstacles, bridges still provide important links between sectors and due to their limited number and distinctive characteristics, they make excellent landmarks.

9) Top Six Model Needs

Objects on the Top Six Model Needs were assigned values based on their placement on each participant's listing. Objects that were designated as the most important items were assigned a value of 6, the second most important item as 5, the third were assigned a value of 4, the fourth most important as 3, the fifth most important as 2 and the least most important as 1. After assigning these values for each of the participant's selections, the numbers for each object were added to determine their overall value. The objects were then ranked in order from highest to lowest totals and displayed on a bar chart (Figure 4.33).

Terrain elevation is the major focus of most participants. Hills, ridgelines, spurs, and fingers rarely have major changes in their shape making them excellent navigation cues. The next most requested items were linear objects such as roads, trails, rivers, and streams. These objects help to identify boundaries within our environment and provide directional cues. Man-made structures were next on the list of items desired by the participants. Trees and clearings were included but, not placed high of the list of needs. Other directional tools such as compasses were also noted. The frequency of items included on the top six list bears a striking resemblance to the order in which the objects were placed on the model developed for this experiment (Chapter III, Section C).

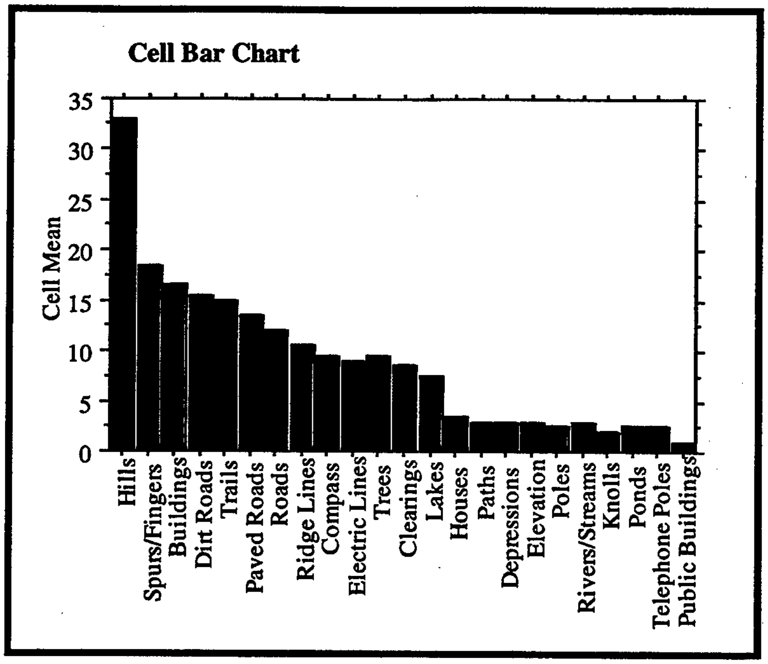


Figure 4.33. Cell Bar Chart for Model Needs (Top Six Model Needs)

Using the items identified as the most essential for use in a virtual environment, a stripped down terrain model could be created which portrayed only elevation changes, linear features, and landmark models. Vegetation could be represented by color coding the terrain skin like a map or placing colored walls indicating the type of vegetation and its height. Based on the results of this experiment, one would expect that the symbolic nature of the VE would assist participants in identifying prominent landmarks while reducing the confusion created by diverse and dense vegetation. This could help to focus participants on key features and enhance navigational performance.

6. Simulator Sickness

During the experiment, a tendency for simulator sickness showed for the one pilot and two VE participants who attempted to run a clean route through the model. These participants were all able to make it past Control Point 4 before stating they felt ill. Non of the participants made it past Control Point 6 before they had to stop and leave the room. Participants were given a time credit if they felt sick and had to step away from the model. After a five to ten minute break, the participants returned to the model. None of them were able to make it past Control Point 7 before feeling ill and stopping their use of the simulator.

The simulator sickness could be due to one or more factors. When the frame rate of the model is less than 30Hz [PAUS 92], and the screen refresh rate is less than 70Hz for color monitors [BAIL 89], equilibrium problems may occur. The problems occur as individuals identify one rate of motion with their peripheral vision while other neural processes perceive a different rate of motion [VAN 90] [EBEN 92]. The critical fusion frequency is achieved when the refresh rate has reached a level where a steady image is attained; normally this is approximately 60Hz [FOLE 97] [THOM 97]. However, this rate can fluctuate plus or minus 20Hz depending on the individual [ROGO 83].

The spinning of the billboards and the popping of the forest walls may also have played a role. As participants moved through the model, the trees would rotate as they passed by the participants' heads. This may have caused equilibrium problems between the middle ear and the optical cues. A participant running a final route also concentrated more on the model, taking fewer breaks to look at the map. The constant staring at and motion of the model may have played a factor in participants succumbing to simulator sickness.

The fact that none of the participants was able to complete a clean run of the VE may have impacted their ability to complete the actual course with limited errors and map checks. The best performance of any VE participant was by Virtual Environment Participant #1 who reached Control Point 7 before stopping the use of the VE due to simulator sickness.

7. Distinguishing Terrain Elevations

During the execution of the course, all participants showed some difficulty with locating Control Point 4 (Chapter IV, Section B.13). For most participants, this difficulty arose as they misread the map and thought the control point was located on a hill instead of in a depression. This same problem was apparent in all participant groups. The map only participants demonstrated this problem the most. Real World participants encountered this problem during the training phase and one participant was never able to overcome the error in time to locate the control point. Surprisingly, two of the VE participants also displayed this problem, both of whom failed to locate CP4 during the evaluation phase. These same participants had difficulty locating the control in the VE. The exploration of the environment by the real world participants and virtual

environment by the VE participants placed most of the participants in the correct vicinity of Control Point 4 unless a participant took the wrong trail enroute to the low ground.

This indicates that identifying the difference between hills and depression on a map is difficult for some individuals. With a time-compressed study of the map and the environment, many people failed to properly identify depressions. Study of a VE or the actual terrain may assist in identifying the improper interpretation of the contour lines and helps individuals construct a more accurate three dimensional representation of the terrain for their own mental map.

8. Need for Land Marks to Locate Control Point

Participants who recognized that Control Point 4 was in a depression and not on a hill encountered problems pinpointing the control since it was in a shallow pit surrounded by knee high grass and brush. The dense low-level vegetation, positioning of the control point below ground level, and the limited landmarks in the vicinity of the control point made locating the control difficult. The participants who used the lone tree 17.5m to the west or the jetty of brush 21m to the south of the control as a landmark had the least difficulty locating Control Point 4. Real world Participant #5 was unable to locate CP4 during the training phase but, realized before he underwent the execution phase that if he went to the tree 17.5m west of the control and worked his way back, he would have better luck in locating the control. He implemented this strategy during the execution phase and walked straight into Control Point 4.

Control Point 2 was also positioned below ground level. Real world participants showed difficulties locating this control point (Chapter IV, Section B.13) although a very distinctive landmark, a shed, was located less then 20m to the east. Most participants who showed difficulty with this control point veered to the north of the flag and searched the terrain to the north and west. Participants who used the shed as an anchoring point and followed the edge of the trees to the south of the shed had little to no difficulty locating the control.

Control Point 7 was positioned below ground level in a trench line. Participants who made it this far showed little difficulty locating the control. Most participants approached the control from the east and walked straight into the end of the trench line.

Other participants intersected the trench somewhere to the west of the control and followed the trench to its east end where the control was located.

The positioning of controls below ground level made them difficult to locate. However, the successful use of landmarks in the vicinity of the controls made the controls easier to locate. Participants who failed to recognize or utilize easily identifiable landmarks found themselves confused and off course. The more distinct the landmark, the easier it was for participants to fix their position in the vicinity of the control and develop a search plan to locate the control. Submerged controls located at the end of linear landmarks or close to very distinct landmarks were easier to locate than submerged controls located in areas with limited or indistinct landmarks.

Effort should be taken to identify and replicate easily identifiable landmarks in the VE to assist in locating items or fixing user positions in areas that can be confusing or to assist in locating objectives that are well concealed. If not, confusion will occur while navigating in the VE which can transfer over to problems with navigating in the actual terrain.

9. Correlation Between Disorientation in Virtual Environment and Disorientation in Real World

A review of training and execution phase routes for the VE and the real world participants indicates a possible correlation between the locations individuals where disoriented during the training phase and the locations they became disoriented during the execution phase. Most participants showed difficulty in maneuvering between Control Point 3 and Control Point 4. This was the first leg that required participants to traverse a straight-line distance of more than 300m.

Further research is needed to determine if there is a direct correlation between locations individuals become disoriented in the VE and were they become disoriented in the real world. If there is a link between the two, VEs can be used to validate mission routes and to assist decision-makers in predicting mission success probabilities. Virtual environments could also be used to identify trouble spots to bypass, conduct map checks, or disambiguate landmarks to ensure individuals do not become lost.

10. Banker Participants vs Goerger Participants

a. Differences in Models

The model used in MAJ Banker's experiment [BANK 97] was a non-real time representation of the environment developed using a golf course creator tool. The tool allowed for a very detailed model that had many characteristics of a map. The surface of the model was colored in a fashion that produced clean edges between the different types of vegetation. This gave the surface a map equivalent characteristic and provided the users with the ability to easily distinguish the difference between forested areas and clearings. The differing grass colors produced an effect similar to moving from covered terrain to open terrain as it delineated region changes. Since the model was developed using a golf course tool, users had to select which portion of the course they wished to explore and teleport between holes in order to view different portions of the model. This was not a seamless transition, as it required participants to refer to a master layout to determine which golf course hole and orientation they deeded displayed.

The model used in this experiment was a real time representation of the environment in which users could seamlessly traverse the entire course area. The relatively uniform color of the model surface covered with an aerial photograph helped to render shadows but, provided no sensation of having an overhead canopy. Appendix P.1 outlines some of the other differences between the two models, the real world, and the map only training conditions.

b. Similarities in Performance

To make comparisons between the two experiments, participants' experience levels for this experiment were reclassified (Appendix O.2) in accordance with MAJ Banker's participant experience level criteria [BANK 97]. Although performance levels were lower in this experiment compared to the Banker experiment, relative comparisons can be made between training conditions and ability groups for the two experiments. Similarities are shown for Total Error Distance by Ability Group (Figure 4.34), Distance Per Error by Ability Group (Figure 4.35), and Map Checks by Ability Group (Figure 4.36). This indicates that MAJ Banker was correct in his conclusions that ability group has a limited impact on a participants ability to recognize and recover from an error.

Figure 4.34 displays Total Error Distances based on Banker Ability Groups for participants in this experiment with a lower score indicating better performance. The results do not indicate statistical significance between the two groups, $\underline{F}(1,13) = 1.702$, $\underline{P} = .2147$. Direct observation suggests that participants in the Beginner Ability Group traveled further off their planned route than the Intermediate participants who were better able to maintain their planned course. This fact is relevant only when viewed in context with errors committed or total route distance. A participant who traveled 300m off their planned route and crossed over 3000m of the planned course, performed better than a participant who traveled 2000m, 250m of which was off their planned route.

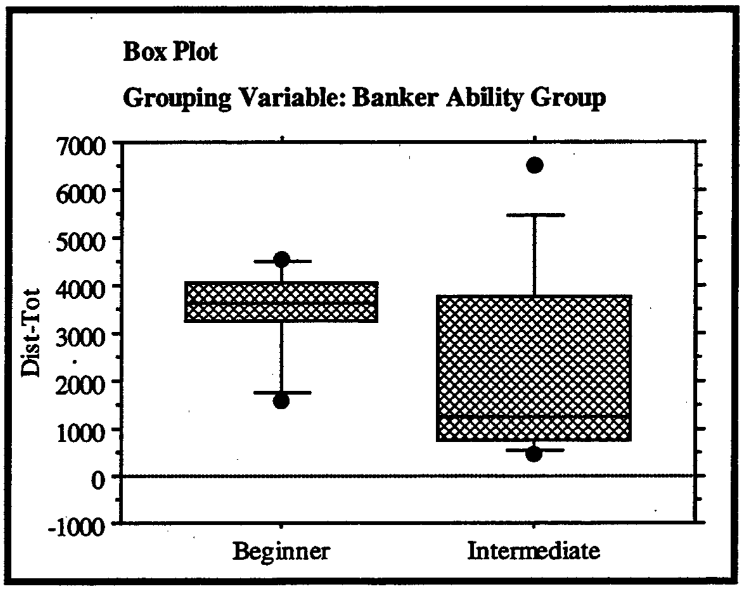


Figure 4.34. Interaction Box Plot for Total Error Distance (Banker Ability Group)

Figure 4.35 displays Distance Per Error based on Banker Ability Groups for participants in this experiment with a lower score indicating better performance. The results do not indicate statistical significance between the two groups, $\underline{F}(1,13) = 1.847$, $\underline{P} = .1973$. Direct observation suggests that participants in the Beginner Ability Group traveled further per error committed than Intermediate participants who were better able to identify when they had deviated from their planned route. Beginner participants had a more difficult time recognizing their errors, fixing their position and orientation in the environment, and developing strategies to recover from their errors. This is to be expected since their navigation skills were limited in comparison to the Intermediate

navigators who had a better understanding of the task and a higher level of confidence in their skills.

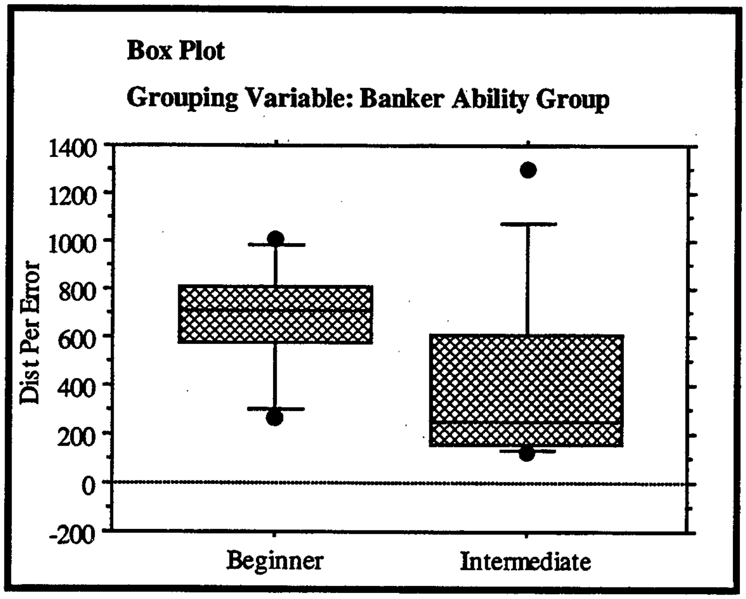


Figure 4.35. Interaction Box Plot for Distance Per Error (Banker Ability Group)

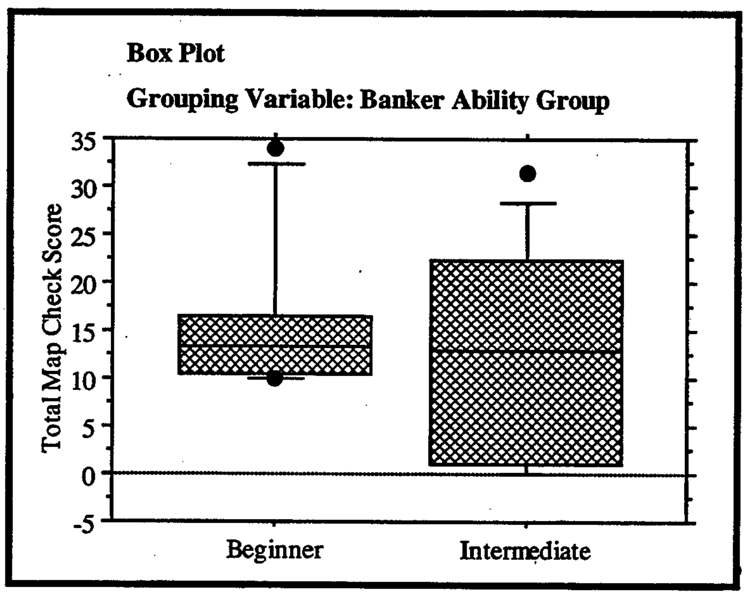


Figure 4.36. Interaction Box Plot for Map Checks (Banker Ability Group)

The Map Checks of the two conditions is shown in Figure 4.36 with a lower score indicating better performance. The means between groups does not indicate a statistical difference, $\underline{F}(1,13) = .447$, $\underline{P} = .5154$. Direct observation suggests that participants in the Intermediate Ability Group had a greater variance in the number of map checks performed per participant than Beginners. This, in conjunction with the number of errors

committed, indicates that many intermediate participants performed maintenance map checks to ensure they were still on their planned route.

c. Differences in Performance

Although MAJ Banker's thesis did not discuss the following measures, there is a difference in performance between participants in his study and participants in this study for Controls Attempt (Figure 4.37), Controls Found (Figure 4.38), Errors Per Control Attempted (Figure 4.39), and Distance by Training Condition (Chapter IV, Section A.4.b). Measurements for MAJ Banker's participants (Appendix P.2) indicate a more level performance across ability group, where this study indicates better performance by individuals rated as intermediates over those rated as beginners by the criteria outlined in MAJ Banker's experiment. Figure 4.37 displays the Controls Attempted based on Banker

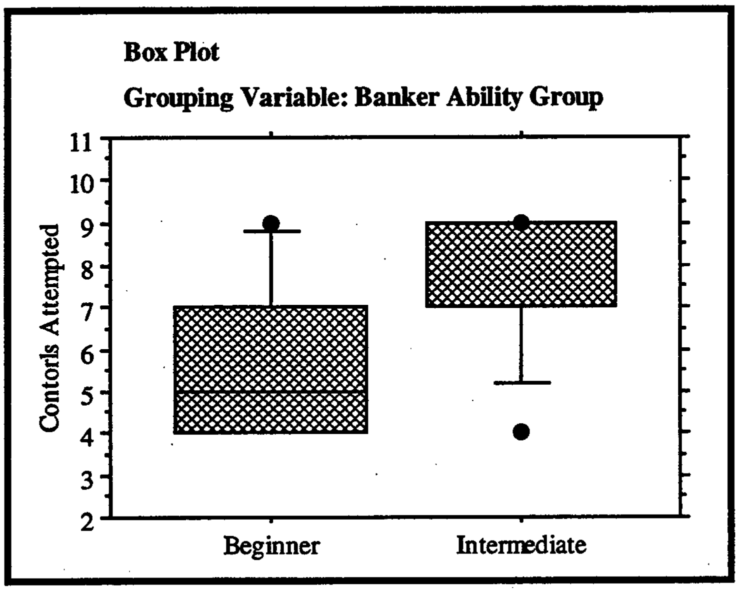


Figure 4.37. Interaction Box Plot for Control Attempt (Banker Ability Group)

Ability Groups for participants in this experiment with a higher score indicating better performance. The results suggest a statistical significance between the two groups, $F(1,13) = 5.226$, $P = .0295$. The graph implies that participants in the Intimidate Ability Group are more likely to attempt a control than participants who are classified as Beginners.

Figure 4.38 displays the Controls Found based on Banker Ability Groups for participants in this experiment with a higher score indicating better performance. The results indicate statistical significance between the two groups, $F(1,13) = 5.987$,

$\underline{P}$ = .0295. The graph suggest that participants in the Beginner Ability Group are less likely to find as many controls as participants who are classified as Intermediates.

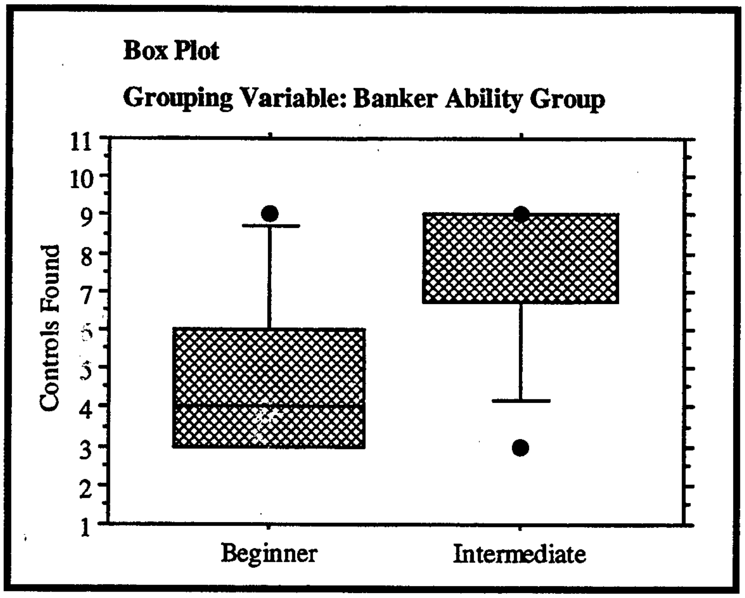


Figure 4.38. Interaction Box Plot for Controls Found (Banker Ability Group)

Unlike the Banker study, when comparing controls found by treatment group and Banker Ability Group, the Intermediate VE participants did not locate more controls than their real world and map participant counterparts (Figure 4.39). The plot indicates no

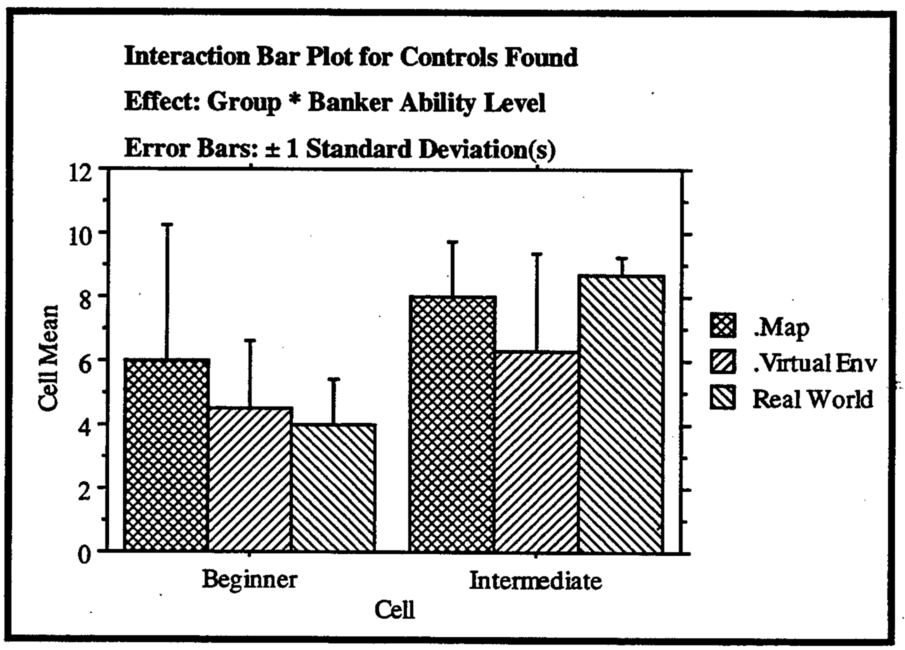


Figure 4.39. Interaction Bar Plot for Controls Found
(Treatment and Banker Ability Group)

significance between training conditions based on Banker's Ability Levels. The difference in performance between Banker's results and this experiment's findings is due to the more simplistic nature of the Banker model. Since participants could not move quickly through Banker's virtual environment, they were forced to focus their efforts when using the model (Chapter IV, Section B.10.d). In other words, for the Banker study, the VE and map groups were nearly identical. If intermediate VE participants in this study would have focused their efforts around control points and major decision points utilizing the teleport option and top down view more, their ability to find control points would have been more comparable to Banker's participants.

The Errors Per Controls Attempted of the two conditions is shown in Figure 4.40 with lower score indicating better performance. The means between groups does not indicate a statistical difference, $\underline{F}(1,13) = 3.757$, $\underline{P} = .0746$. Direct observation suggests that participants in the Intermediate Ability Group make fewer errors per control attempts which implies they are better able to stay on their planned routes than Beginners.

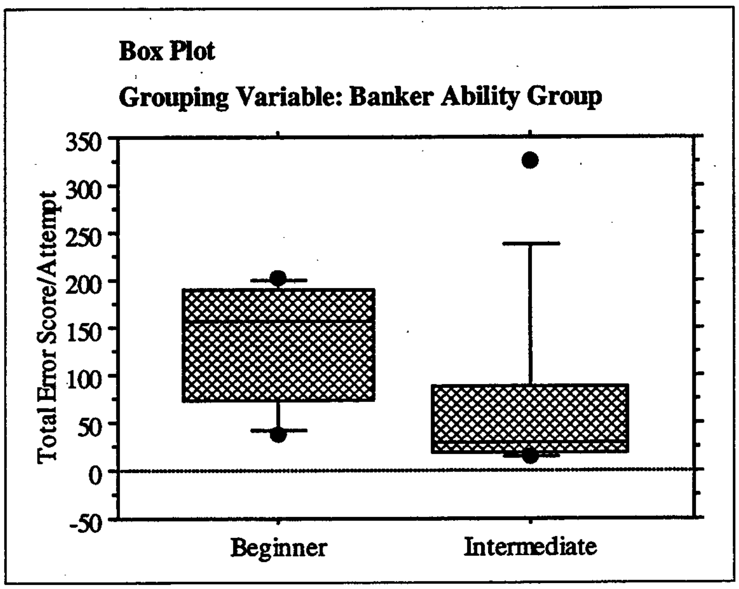


Figure 4.40. Interaction Box Plot for Errors Per Controls Attempted (Banker Ability Group)

Similar to the comparison of controls found by treatment group and Banker Ability Groups, the Intermediate VE participants did not attempt more controls than their real world and map participant counterparts (Figure 4.41). The plot suggests no significance between training conditions based on Banker Ability Levels. Once again, the difference in performance between the Banker's findings and this experiment's

results is due to the more simplistic nature of the Banker model (Chapter IV, Section B.10.d).

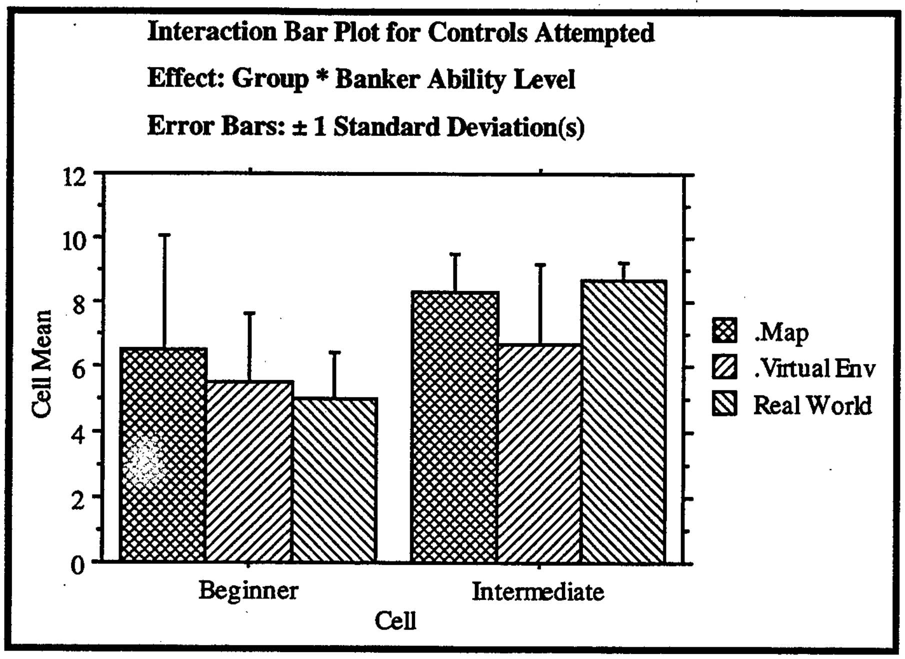


Figure 4.41. Interaction Bar Plot for Controls Attempted (Treatment and Banker Ability Group)

An identical 2-way ANOVA was run comparing Map Check Score and Total Error Distance by treatment group and Banker Ability Groups. Unlike the Banker experiment, no statistical significance was shown between training conditions based on Banker Ability Levels for Map Check Scores, $\underline{F}(2,9) = 1.602$, $\underline{P} = .2539$. Nor was there any statistical significance shown between training conditions based on Banker Ability Levels for Total Error Distance, $\underline{F}(2,9) = 1.522$, $\underline{P} = .2695$. The Banker study found that his VE had a statistically significant increase in performance in these two areas for intermediate participants. Banker's findings were not supported by this study. This is due to differences in the type of navigation experience between the two participant pools.

d. Reasons for Performance Differences

As a whole, Banker's participants performed better than the participants of this experiment. This is due to differences in the participant pools and the structure of the experimental design. MAJ Banker's participants were more experienced in sports orienteering and the use of orienteering maps than participants of this experiment. They were also more familiar with running orienteering courses in typical central California

coastal terrain since many of them had participated in events in the San Francisco Bay area, Santa Cruz Mountains, and Monterey Peninsula. This resulted in a difference in the *type* of experience each intermediate group possessed and the kind of information they were able to extract from the VE, map, and natural environment. Due to the inexperience of many of the participants in this experiment, their planned routes were more difficult than those in the Banker experiment. If this experiment's participants had more experience with navigating in central California coastal lands, they would have been able to extract more pertinent information from the study materials and improved their overall navigational performance. This indicates a possible use of virtual environments to train navigation skills for areas which soldiers may not routinely encounter. If generic navigation skills can be taught through the use of generalized terrain models for desert, arctic, mountainous, jungle, and wooded terrain, the VE would provide a useful tool for a commander's training program.

The experimental outline of MAJ Banker's thesis was less intrusive to the participants. All pointing tasks were conducted prior to the execution of the planned route. Once the planned route was initiated, no planned interruptions were made. For this experiment, pointing tasks were interjected at Control Points 2 and 4. This interrupted the flow of the planned route and may have had an effect on participant recall of their planned route. However, most participants showed little difficulty in navigating to the control points immediately following the Wheel Tests. Participants also received assistance from monitors if they were off course for more than 15 continuous minutes and were not making progress towards their designated control (Chapter IV, Section A.4.a).

The poorer performance of this experiment's VE participants is due to their reduced ability levels and the ability of MAJ Banker's Non-Real Time VE to provide an exocentric as well as an egocentric view simultaneously. This reduced the effort required by participants to locate themselves in the environment since the computer model resolved this issue for them. Since the model was a non-real time model, participants teleported between control points and decision points in the environment instead of conducting cross-country movement through the model. Participants in the real time model had to navigate through the VE and determine their location as they moved. This required them to utilize the navigation cycle (Appendix Q) during the study phase and

use training time to move through terrain which provided few disambiguating features to assist them with navigating through the actual terrain. If participants had used the real time VE to explore the area around the control points and to identify the differences between key decision points along their planned route, their performance would have improved.

11. Map Resolution

The map used for this experiment far exceeds the capabilities of most maps used during traditional military operations or orienteering competitions for its level of detail. Any dismounted infantry or special operations soldier would treasure a map of such detail when entering into a new area of operations. Most military operations maps are at a scale of 1:50,000 or 1:24,000 (Appendix F).

Because of the small scale of the map and the use of orienteering terrain classification markings, participants could glean information from the map that would normally not be available to them. Most participants gave the map above average ratings for clarity, information provided, and ease of use (Chapter IV, Section B.4.a). The increased detail provided participants with enough information that they did not need to use the VE or real world to discover and catalog many landmarks or changes in terrain elevation that would normally be too indistinct to appear on most maps. This resulted in map group participants performing much better than would normally be expected of an individual who was provided with only a map, objective photos, and objective locations.

12. Resolving Ambiguities In Mental Maps

When participants began the course, they first had to identify their position and orientation (Appendix Q). Once this was accomplished, they checked their mental maps and list of instruction to determine their course of action. Once movement began, they were continuously cycling through a series of mental processes to verify their position, orientation, mental map, and route. While updating their mental maps, each group was faced with a unique set of issues.

Map participants tended to navigate using *propositional knowledge*, a list of directions, that when linked together would lead them through the course. This represents exocentric knowledge of the environment that is spatial but, not temporal which meant that the fidelity of the environment did not encumber map participants.

Often they concentrated on more definable characteristics of the course such as buildings and trail intersections as well as the distance between them, rather than less distinguishable objects such as trees. This required the translation of propositional knowledge into ambiguous *static imagery* (Appendix Q). Since their imagery was indistinct, map participants did not panic when their mental maps did not match the actual imagery they encountered. Participants did have to resolve the differences between perceived distances on the map and actual distances on the ground as well as visualizing the different categories of terrain depicted on the map. Participants who paid close attention to the first couple of trails they encountered during the initial portion of the course, quickly resolved this issue and showed little difficulty with perceived distances for the rest of the experiment.

Real world participants were faced with a different set of issues as they attempted to resolve differences in their perceptions of the real world and the actual terrain they were standing on. Similar to the map participants, those real world participants who paid close attention to the first couple of trails they encountered during the initial portion of the course, quickly resolved the distance issues and showed little difficulty with perceived distances for the rest of the experiment. Those real world participants who failed to resolve this issue during the training phase showed difficulties with judging distances during the middle portion of the course.

Although real world participants had traveled the terrain once before, their perception of the environment was based on *dynamic imagery* (Appendix Q). Dynamic imagery is similar to a mental movie. The navigational performance of real world participants is based largely on how well they developed their mental movie during their initial run through the environment. If participants make it only partially through the environment or become confused along their route, their movie becomes a poorly edited collection of three-dimensional clips. The movie remains that way until they can make a clean run through the course editing their movie, clarifying discrepancies as they move through the environment. Real World Participant #1 demonstrated difficulties in editing his mental movie due to the inordinate amount of time he spent looking for Control Point 3 during the training phase. He searched the area between Control Point 2 to the western boundary looking for Control Point 3. Because of this, his mental map and dynamic

imagery of the environment was cluttered with ambiguous representations. As a result, he was unable to locate Control Point 2 without crisscrossing the area between Control Point 1 and Control Point 3 four times. Participants with well edited mental movies performed movement along their planned route better than participants who had poorly edited depictions of the environment. During the training phase, real world participants showed the same difficulty with resolving distances that the map participants initially encountered during their execution phase as they dealt with resolving differences in propositional knowledge with the actual terrain.

Virtual environment participants had to deal with many of the same issues which the real world participants faced in resolving inconsistencies with their dynamic imagery of the environment and their perceptions of distance. Misperceptions of distances and sizes from use of the VE caused many VE participants to over estimate the distances they need to travel when operating on the actual terrain. The placement of a HMMWV at the start point of the VE did not appear to alleviate these perception issues. Virtual Environment Participants #1, #2, #3, and #5 all commented on their initial difficulty with resolving distance during the execution phase of the experiment. Similar to the map and real world participants, those VE participants who paid close attention to the first couple of trails they encountered during the initial portion of the course quickly resolved the distance issues and showed little difficulty with perceived distances for the rest of the experiment.

To compound the issues of perception, VE participants had to resolve differences between the model environment and the actual terrain. Differences in vegetation density and complexity as well as perspective issues required additional mental manipulations in the environment. Participants who interpreted the vegetation in the VE as symbolic representations of vegetation did not regard vegetation as a landmark object and were able to disregard the vegetation while moving through the actual environment. This allowed them to focus on more distinguishable landmarks.

Participants are willing to accept oversights with maps and VEs, but, are unwilling to accept errors (Figure 4.42). If the map or VE is missing something that is present in the real world, individuals accept this as changes in the environment since the model or map was developed. In other words, the map and VE are assumed to be a

subset of the real environment. They resolve the differences with their mental map by adding the missing feature. If something appears on the map or in the VE, individuals expect to see that same object or feature in the real world. When individuals do not see the feature in the real world, confusion may result and they question the validity of the map or VE. This can result in total mistrust of the mental map created from a physical map or VE.

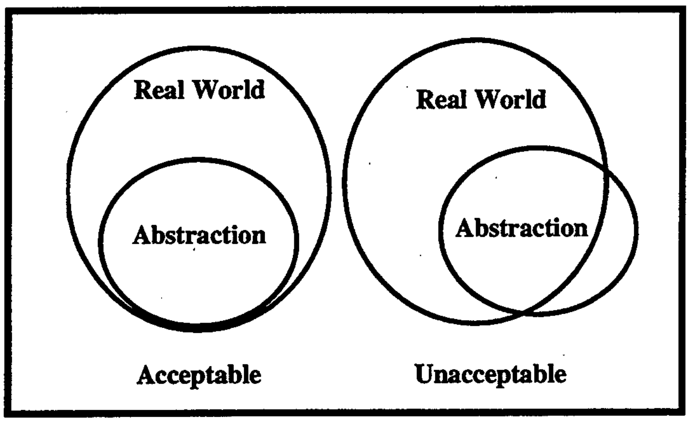


Figure 4.42. Venn Diagram of Real World Abstractions

It is better to leave something off of a map or out of a VE than to misrepresent it. Misrepresentation of objects or features on maps and in VEs creates confusion and mistrust which leads to individuals abandoning their mental maps and questioning their knowledge of the environment. Ultimately this results in a large drop in navigational performance. Exposure to maps still provides ambiguity issues. Maps are excellent at providing propositional knowledge that produces superior static imagery for route knowledge with one caveat. Static imagery is easily fooled by parallel errors (Chapter IV, Section A.4). Map Participant #3 felt his biggest problem was resolving distances. This lead to his parallel errors at Control Point 2 when he was searching the clearings to the north of the building instead of to the west. With a more dynamic image of the area, he would have been able to recognize the difference in the clearings such as the open area to the south of the clearing in which CP2 was actually located. Map Participant #4 experienced parallel errors in locating Control Point #3 since from the map study, he was unable to distinguish the differences between the buildings located in the vicinity of CP3.

The exposure to the actual environment or an accurate VE can help to resolve these ambiguities by filling in the gaps by changing static imagery into dynamic imagery which can clarify discrepancies that lead to parallel errors. Virtual Environment Participant #1 commented that he wished he had used the model to study the area more carefully around Control Point 4 and Control Point 9. This would have helped him disambiguate the terrain at these locations. Virtual Environment Participant #2 gained tremendous confidence in his location when he saw the building near Control Point 2. As he approached the area from the north, he stated, "I know from the model that I have to go left at this broken down building to find CP1." During the debriefing, he commented that he remembered the pavilion near Control Point 3 from the model which helped him fix his position when searching for the control.

13. Map Checks vs Errors

MAJ Banker briefly discussed the correlation between map and compass checks and distance off route [BANK 97]. His results indicated that the further a participant was off the planned route the more likely the participant was to conduct a check. A similar simple regression was performed in this experiment to see if the same findings would hold true. For this analysis, the Normalized Average Distance Per Error (Chapter IV, Section A.4.b) and the Normalized Map Check Score (Chapter IV, Section A.4.c) for each participant was used. These two measurements were used because the measurements are normalized to take into account the number of errors committed and the number of control attempted.

The results were comparable to the Banker study. The results show a direct correlation between the distance participants were off their planned route and the number of checks they performed, $\underline{F}(1,13) = 32.380$, $\underline{P} = .0001$ (Figure 4.43). The results indicate that participants who are on their planned route are more confident in their performance and conduct fewer checks. Once participants recognize they are off their planned route, they conduct checks in accordance with the distance they have deviated from their planned route. The further participants were off their planned route, the more checks it took them to return to the proper route.

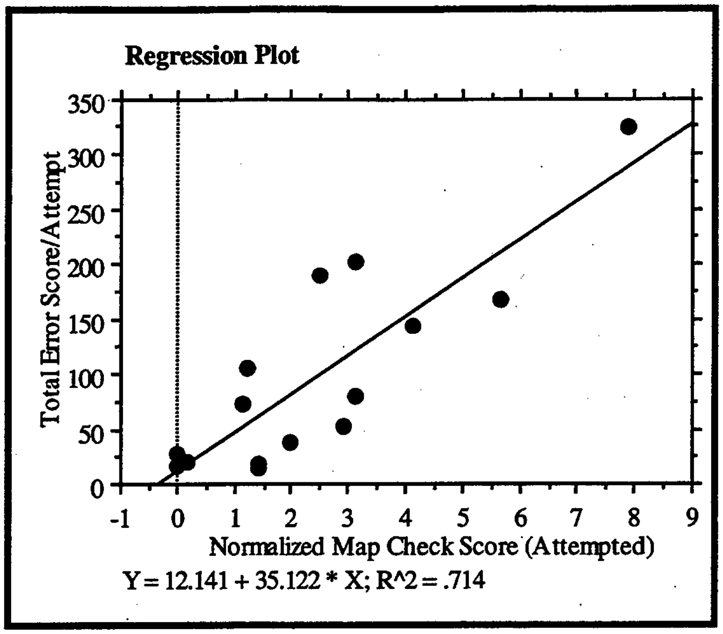


Figure 4.43. Regression Plot for Total Error Score Per Control Attempted vs Normalized Map Check Score

14. Average Distance Off Route

In MAJ Banker's thesis, he briefly reviews the distance participants veered off their planned route per control point [BANK 97]. His conclusions indicated that the real world participants' performance declined as they traveled further through the course because they were unable to explore their entire routes during the training phase due to the one-hour time constraint. Similar conclusions were drawn from this experiment based on the fact that only two of the real world participants were able to make it further through the course on the execution phase than on the training phase. This issue can be addressed by time compressed training in a VE that allows individuals to more rapidly explore an environment through increased speed of movement or teleportation.

Making comparisons to MAJ Banker's scatter plot of Treatment Group Distances Off Route by Control [BANK 97] and Figure 4.44, we see an interesting correlation between the average distance per participant on Control Point 4. The notably marked increase in average distance per participant indicates that Control Point 4 presented participants of both studies with a more difficult task. The reasons for this were discussed previously (Chapter IV, Sections B.6 and B.7).

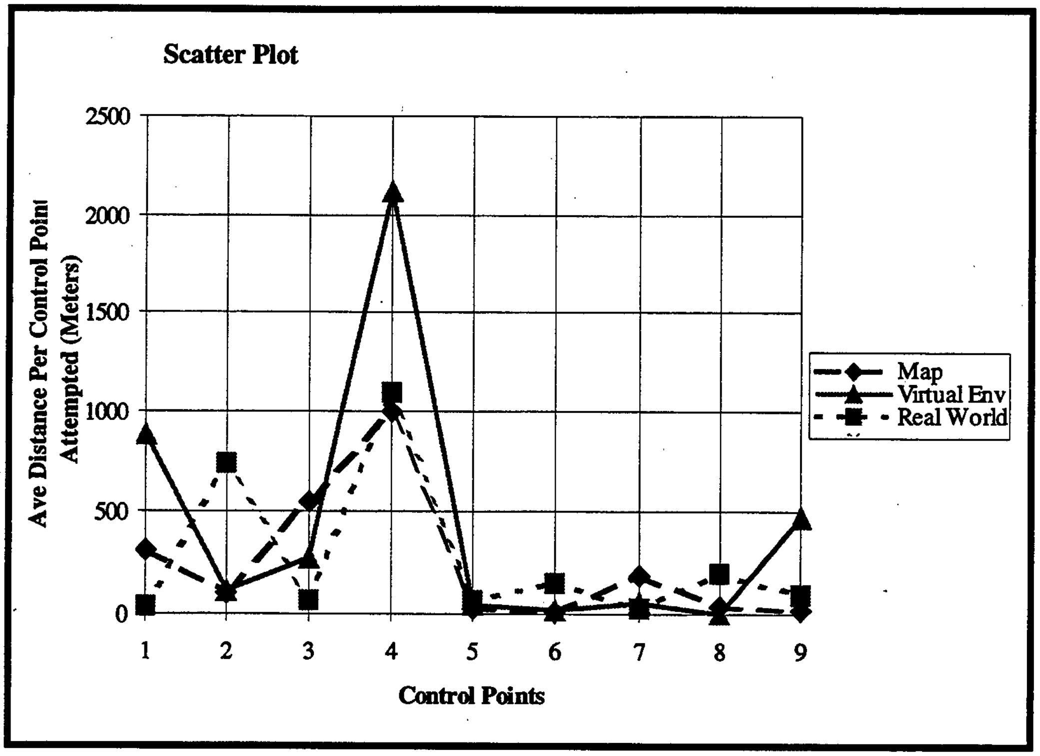


Figure 4.44. Scatter Plot of Average Distance off Route Per Control Attempted

Although Figure 4.44 indicates VE participants having even more difficulty with Control Point 4 than the real world and map only participants, Figure 4.45 indicates that the difficulty with the control is actually more uniform across the groups. This scatter plot displays a normalized distance per error.

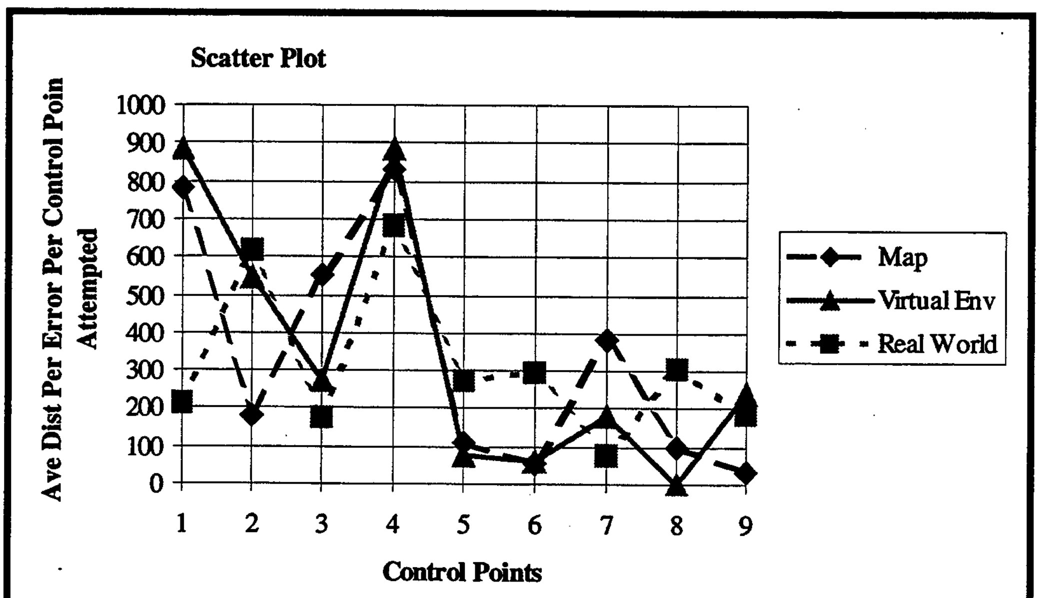


Figure 4.45. Scatter Plot of Average Distance Per Error Per Control Attempted

Both graphs indicate a more level performance after Control Point 4. However, only 11 participants made it past Control Point 4 with only 66% of the participants making it past Control Point 6, and only the better navigators making it through the course. The plot shows that once an error is committed, the mean performance for participants demonstrates the same amount of difficulty in recovering from the error for Control Point 4 regardless of training condition.

Figure 4.45 also indicates that map and VE participants had more difficulty recovering from errors during movement from the starting point to the first control. This is due to both groups of participants attempting to resolve resolution differences between their mental maps and the real world (Chapter IV, Section B.11). Virtual environment participants showed a marked improvement in their ability to recover from their errors from Control Point 1 to Control Point 3, but, ran into difficulty with Control Point 4. After Control Point 4, performance for all remaining participants leveled off except for a decrease in performance at Control Point 7 for the map participants. The real world participants demonstrated the most difficulty of all participants who executed Control Points 5 through 9. This supports MAJ Banker's conclusions that real world participants have more difficulty with the later stages of the course because of their inability to traverse this section of the terrain during the training phase.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. General Conclusions

This experiment studied the effects of training methods on spatial knowledge of a natural environment given a one-hour exposure to a high resolution 1:5,000 orienteering map, access to the orienteering course, or a high fidelity real time virtual representation. The following conclusions are drawn from both the quantitative and qualitative results:

a. Experiment training conditions show no significant effect on an individual's ability to obtain and demonstrate spatial knowledge of a natural environment (Chapter IV, Section A.6).

b. Spatial ability plays a significant role in an individual's ability to obtain and demonstrate spatial knowledge of a natural environment (Chapter IV, Section B.4).

c. Exposure to the actual terrain or a virtual representation of the terrain eliminates ambiguities in an individual's mental map by providing dynamic imagery to disambiguate propositional knowledge gained from maps (Chapter IV, Section B.12). However, there are other issues with walking the ground or VE that prevent these training tools from being better than a really good map for short exposure durations.

d. A high resolution 1:5,000 orienteering map provides an inordinate amount of detail which is uncommon in typical maps used for military operations and has a significant effect on an individual's ability to obtain and demonstrate spatial knowledge of a natural environment (Chapter IV, Section B.11). It's hard to beat a really good map.

2. Performance by Study Group

Based on the use of a 1:5,000 orienteering map and a high fidelity real time VE, the results suggest that provided with an hour to study the environment and plan a route, map only participants gained more spatial knowledge of a 1km square piece of terrain than VE participants. VE participants performed on par with real world participants. Overall comparisons of results indicate that map participants outperformed real world participants who outperformed VE participants in route knowledge. Results suggest that

VE participants had slightly better survey knowledge than map and real world participants.

3. Performance by Spatial Ability

Using a high resolution 1:5,000 orienteering map and a high fidelity real time VE, results suggest that provided with an hour to study the environment and plan a route, participants with above average spatial ability scores gain more spatial knowledge of a [illegible] square piece of terrain than participants with below average spatial ability scores. Overall comparisons of results indicate that participants with above average spatial ability scores outperformed those with below average spatial ability in route knowledge. Results suggest that above average spatial ability participants had better egocentric knowledge of the environment and slightly better excocentric knowledge than below average spatial ability participants.

4. Mental Maps

Behavioral analysis in this experiment suggests that the earlier models of navigation based on the assumption that individuals, while navigating, make decisions depending on a comparison between what they see versus what thy expect to see [[illegible] 84] [JUL 97], are only partially correct. Virtual environments and the real world provide us with mental imagery of our environment. Maps only provide us with propositional knowledge that most people translate into an ambiguous series of static mental images as they move through the environment. Exposure to VEs or the real world assists individuals in filling the gaps, resulting in dynamic mental imagery, disambiguating images created by the study of a map. With enough exposure to the real world and VEs, we can resolve any discrepancies in our mental imagery which enhances our confidence in our navigation through the environment. An individual's preconceived egocentric view, whether developed from the study of the real world or VE, provides a strong mental image. A participant cannot help but refer to this mental image, even if it is incomplete or confused.

5. Map Resolution

The performance of the map only subjects may have been skewed based on the scale and resolution of the map used for the experiment. This map (1:5,000 orienteering map), provided more information than is usually available on maps used for most military

operations. Providing participants with a map of less resolution will surely produce worse results for the map only group and improve the perceived performance of the VE and real world groups.

B. SIGNIFICANCE

1. Study Method

Given a limited timeframe and highly detailed maps, individuals will gain more information about the target environment than subjects afforded high fidelity real time models. Given less than an hour time to prepare for a mission, individuals should concentrate more on map study and route memorization than general terrain familiarization if they wish to maximize their performance. This fact helps to limit expenditure of resources and reduces the possible confusion of mission forces, allowing them to focus on those assets which will best assist them in preparing for the operation.

2. Spatial Ability

Identifying individuals with above average spatial ability will assist in predicting which personnel may be better suited as navigators. If these visual and organizational traits can be identified and taught, it will assist in training individuals to perform navigation tasks in a manner which will improve their spatial knowledge and overall performance in the area of operations.

3. Mental Imagery

Giving a relatively unconstrained timeline for mission preparation, individuals can make numerous runs through a VE. This will allow individuals to edit their mental movies providing them with an excellent three-dimensional mental representation of the environment to assist them during navigation.

4. Map Resolution

Maps with high resolution provide a tremendous amount of information. If individuals have a limited amount of time to prepare for a mission, a high-resolution map is a better tool for gaining spatial knowledge of an area. The same detail required to produce a high fidelity VE is the same information required to produce a high resolution map which depicts vegetation densities and building orientations. Producing a high-resolution map is less time intensive and results in a two dimensional representation which is easily carried and studied. With a limited amount of time for mission

preparation, resources should be placed on producing a high-resolution map that can be quickly mass reproduced and distributed to the mission force. This will save precious resources while affording individuals with the best training tools for the available time.

C. CONTRIBUTIONS

The experiment implemented two tests that were developed to help test an individual's excocentric and egocentric knowledge of the environment. These tests were essential in determining if individuals had gained only route knowledge of the environment or if they were able to obtain and demonstrate survey knowledge.

1. Wheel Test

To measure egocentric knowledge of the environment, the Wheel Test was used. This test is a variation of the one initially developed for use in an experiment conducted to test the transfer of spatial knowledge from a VE to a complex man-made structure [GOER 98]. The test measures an individual's ability to identify the direction to several locations within the environment without providing the individual with directional cues (Chapter III, Section G). It requires that individuals understand their relative position within the environment with regards to locations they have or will be visiting while navigating through the environment. Variances from actual measurements are calculated and combined for comparison with other participants.

2. Whiteboard Test

To measure exocentric knowledge of the environment, the Whiteboard Test was used. This test is also a variation of the one initially developed for use in an experiment conducted to test the transfer of spatial knowledge from a VE to a complex man-made structure [GOER 98]. The test measures an individual's ability to identify the relative position of the control points to one another without any external reference cues (Chapter III, Section G). It requires that individuals understand the relative position of the controls to each other without worrying about a distance scale. Angles between each control point are measured and used for comparison with the actual measurements and to compare against other participant results.

D. FUTURE WORK

1. Displays

During the experiment, participants were exposed to a large three-screen display with over 103° field of view and 4800 square inches of viewable surface. This is done to provide the participant with the largest viewable surface possible. Little research has been conducted to determine which type of display provides the best possible environment for navigating. Single screen, triple screen, head mounted display (HMD), and wide screen views are just a few options available which are easily configured for use at most simulation centers.

Usability participants in this experiment and in Sullivan's helicopter navigation experiment [SULL 98] indicated that the wider field of view dramatically assisted in navigating through the environment. Participants felt they were able to extract navigational cues from the terrain on their peripheries much as they would do in the real world. This suggests that a wide screen or three-screen configuration may be the best display for such training and mission preparation devices. However, these participants were not exposed to either environment using a HMD.

Some users appear to be more prone to simulator sickness than others. This can be due to many factors from direct exposure time to refresh rate (Chapter IV, Section B.6). During this experiment, participants who made it through the environment and were conducting a final run, expressed a feeling of simulator sickness between Control Point 4 and Control Point 5. Each of these participants stopped their movement and took a five to ten minute break before going back into the simulation. None of these participants completed their second trip through the model as they all stopped somewhere between Control Point 6 and Control Point 7 even though they had time remaining.

Further research is needed to determine which display and frame rate are best to reduce the instances of simulator sickness while providing the user with the best possible display for obtaining the information needed to maneuver through the environment.

2. Interfaces

Training and mission preparation occurs in many locations and in many forms. From initial training in classroom type environments to last minute revisions while flying to the mission release point, soldiers are continuously planning, revising, and rehearsing

the mission at hand. Because of this, the interface for computer training devices must be customized to the task to provide the best possible results. However, we don't know what the task to interface relationship is.

To the user, the interface is the system and therefore the interface must optimize system utility while limiting factors that may hinder performance [HIX 93]. Whether it is a keyboard, joystick, mouse, data glove, Polhemus device, locomotion device, or some other interface, the device must be easy to use and provide the user with the versatility needed to maneuver through the environment to provide positive training transfer. Anything less will reduce the effectiveness of the training and could foster negative training effects. Continued research is needed in this area to determine what type of interface is best for simple navigation through a VE.

3. Fidelity Levels

As we increase the capabilities of our hardware and software, the definition of low, medium, and high fidelity models become more diverse. In the early 1970's, people were impressed with the wonderful new game played on televisions called Pong. Today, home gaming systems such as SEGA and Nintendo attempt to dominate the market with football, basketball, baseball, and hockey games that have players who look and perform like their real world counterparts. What was considered "high" fidelity gaming action in the seventies and eighties is now considered low-end computer graphics.

The closer to reality we approach, the less forgiving the user. The user trusts the model to such a degree that any inconsistencies he encounters may cause him to lose confidence in the model representation. Most people understand that a map will have inconsistencies, especially in the area of vegetation. When these same discrepancies appear in a VE, participants seem less willing to accept the shortcomings as minor limitations. People forget that a VE is a tool. Instead they often become flustered with and untrusting of the model.

At some point, as a model mimics reality, close is not good enough and the VE must be near 100% accurate. However, the point where this occurs is unknown. The question is, at what level of fidelity do people stop accepting model shortcomings and begin demanding complete assurance? We may even be to the point where people are more willing to accept a simple model of elevation data covered with an aerial photo over

a model that depicts structures and vegetation which may be realistic but, not completely accurate in placement or appearance for the purpose of navigation.

4. Iterations vs Time Limit

Often participants and soldiers comment that "if I could only do it again, I know I would do it better." They may be correct. Performance as a function of time may be so variable as to be statistically meaningless. Performance may depend more on the number of times the individual is able to maneuver through the environment. Participants in this experiment who were able to explore the environment looking for the control points and then make an additional clean run through the course outperformed those participants who were able to go through the course only once (Table 5.1). However, no statistical significance could be shown due to the limited number of participants in the group.

Test	***1 Run VE Group Means***	***2 Run VE Group Means***	***Participant Pool Mean Score***
Landmark Score (*Higher score is better*)	4.333	8.000	6.709
Total Errors	5.667	6.000	5.133
Normalized Map Check Score	4.127	1.570	2.455
Normalized Error Score	183.833	54.210	98.355
Average Wheel Test Angular Deviation	30.720	19.335	26.767
Average Whiteboard Angular Deviation	23.589	18.056	23.720

Table 5.1. VE Participant Results

This could be due to the opportunity to correct deficiencies in the mental map created as the participant explored the environment on his first trip through the course. To determine the validity of this hypothesis, participants could be placed into three similar groupings of map, real world & map, and VE & map. Instead of being giving an hour, ninety minutes, or two hours to study the environment and plan their route, participants would be allowed to go through the environment twice. The first time through the environment, the participant would be allowed to explore and plan his route. The second time through the environment, the map participant would describe his route without the use of a map. A real world participant would walk his planned route using his map and a compass. The VE participant would execute his route in the VE using his map. Participants would have to navigate or explain their routes with no more than one major or two minor errors before being allowed to move onto the evaluation phase.

Participants could then be evaluated on the number of repetitions it took for them to pass the training phase and the number of errors they committed during the evaluation phase.

Participants in this experiment were also forced to bundle planning and rehearsal into one phase. In order to distinguish between the two, participants should be given ten to fifteen minutes to plan a preliminary route through the environment prior to exposure to the VE or actual environment. During the training phase participants should be allowed to make changes to their initial plan. This will force participants to focus their efforts on planning before they conduct training.

5. Designated Route vs Participant Planned Route

It has been shown that participants can gain path knowledge of man-made environments through the use of VEs [WITM 95]. In this experiment it has been demonstrated that less path knowledge (Chapter IV, Section A.3) and survey knowledge (Chapter IV, Section A.4) is obtained through exposure to a VE than through the use of map study of a high resolution 1,5000 orienteering map.

What should also be studied is the performance of participants provided with a pre-planned route with the performance of participants who have to develop their own route. Limiting the task to studying and exploring a predesignated route would reduce the workload on the participants. This would provide them with more time to concentrate on the task of navigating through the environment instead of planning and navigating. If VEs can impart enhanced route knowledge, they could be useful in mission rehearsal of specific routes.

6. Male vs Female

Past research has suggested that males have better spatial ability and visualization than females [ANAS 63] [MACC 74] [LLOY 76] and may be based on genetics [TAVR 77]. More recent research indicates that differences in spatial ability based on gender are becoming less distinguishable [STUM 89] [WEST 98]. No research has been conducted to see if this is true for natural environments.

In this experiment, the VE group had one female participant. On average, her scores were better than the mean scores for the VE participants and nearly the same as the mean for the entire participant pool (Table 5.2). The female participant had an outstanding Normalized Error Score due to her ability to quickly identify her errors and

construct viable solutions to resolve her situation. Her Whiteboard results indicate a relatively poor exocentric view of the environment. Analysis of her image (Appendix-N, Figure N.76) shows a shift of the control points to the west and south of their correct position. The remainder of her scores were well within one standard deviation of the means for both the VE participants and the entire pool.

Test	***Female Participant***	***VE Group Mean Score***	***Participant Pool Mean Score***
Landmark Score (*Higher score is better*)	6.333	5.798	6.709
Total Errors	6.000	5.800	5.133
Normalized Map Check Score	2.333	3.104	2.455
Normalized Error Score	37.930	131.984	98.355
Average Wheel Test Angular Deviation	26.833	26.166	26.767
Average Whiteboard Angular Deviation	28.154	21.376	23.720

Table 5.2. Female Participant Results

With only one female in the study, no definitive conclusions can be drawn from her performance. However, it brings up the interesting question if gender specific navigation performance is affected by the use of VEs.

7. Colorblind vs Non Colorblind

Past research has neglected the influence of colorblindness on navigation performance in man-made or natural environments. Since navigation is usually a very visual process, this is a major shortfall. In this experiment, there were two colorblind participants, both in the Map Group (M2 and M4). On average their average scores were better then the mean scores for the Map participants and the mean for the entire participant pool (Table 5.3).

Test	***Colorblind Participants***	***Map Group Mean Score***	***Participant Pool Mean Score***
Landmark Score (*Higher score is better*)	7.665	7.398	6.709
Total Errors	5.000	4.800	5.133
Normalized Map Check Score	.690	1.424	2.455
Normalized Error Score	63.125	83.036	98.355
Average Wheel Test Angular Deviation	24.420	26.634	26.767
Average Whiteboard Angular Deviation	20.288	22.227	23.720

Table 5.3. Colorblind Participant Results

With only two colorblind participants in the study, no conclusions can be drawn from their performance. However, since most VEs make more demands on the visual senses than any of the other senses, it brings up the interesting question of color sensitivity and the use of VEs to enhance navigation performance.

8. Experience Level vs Mental Map Development

In this and in MAJ Banker's experiments, much emphasis was placed on the experience of the participant. Little research was focused on analytical ability. The assumption was made that individuals experienced with orienteering or military land navigation would best be suited as participants for this type of land navigation experiment.

One pilot participant for this experiment had less than one week of military navigation training and no experience with orienteering. The participant had the lowest score on the Map Reading Test (70% correct). He scored the lowest on the Santa Barbara Sense-of-Direction Scale (73) and classified himself as a beginner on the Self-Ability Evaluation. He did score above the national average on the Guilford-Zimmerman Aptitude Survey (26.75) and is a Rhode Scholar applicant. On average, his scores were better than the mean scores for the VE participants and the entire participant pool for landmark and route knowledge scores but were much worse for the survey knowledge tasks (Table 5.4).

Test	***Novice Pilot Participant***	***VE Group Mean Score***	***Participant Pool Mean Score***
Landmark Score (*Higher score is better*)	9.000	5.798	6.709
Total Errors	6.000	5.800	5.133
Normalized Map Check Score	1.111	3.104	2.455
Normalized Error Score	35.556	131.984	98.355
Average Wheel Test Angular Deviation	76.167	26.166	26.767
Average Whiteboard Angular Deviation	30.858	21.376	23.720

Table 5.4. Novice Pilot Participant Results

As stated in Chapter 4.B.2, there is significant correlation between performance and the Guilford–Zimmerman Aptitude Survey. Although the inexperienced novice participant showed difficulty with the survey knowledge tasks, he performed very well on the landmark and route tasks. This indicates there may be a correlation between

navigation performance and an individual's analytical abilities, which is independent of experience or training. An individual's analytical ability may impact on the way they organize thoughts and create mental maps. This correlation may lead to the conclusion that certain individuals are more prone to being natural land navigators.

9. Medium vs Time of Exposure

Many military missions and most hostage situations are made more complex by time constraints. Often individuals and teams have only days or hours to prepare for complex scenarios which require detailed precision. These time lines limit resources which can be made available to assist in mission preparations. Research indicates that with limited time and exposure, VEs provide very limited performance enhancement and may even be counter productive [GOER 98].

Due to limited resources and the complexity of the research, many experiments involving the usefulness of VEs to assist in the transfer of spatial knowledge to real world environments have been limited to exposure durations of less than an hour; often only a few minutes. Under these limited exposure times, participants may not be able to resolve the differences between the map and the VE or build an uncluttered and continuous mental map of the real world. Depending on the size and complexity of the model and actual environment, participants may need more exposure time to resolve differences and build a valid mental map of the terrain.

In view of the limited amount of information on a map, the time to resolve differences is less than when developing a mental model from a VE. However, a map cannot display as much information as a VE nor can it resolve errors that may occur from false readings of terrain features, such as mistaking a map depiction of a depression as a hill. A map can provide a rough sketch of the environment with simple references that can easily be confirmed or refuted by the participant as he moves through the environment. If time is limited, a map may give an individual the rough geocentric view of the world needed to make simple movements through the terrain. This may be why the map only group outperforms the VE and real world groups for limited exposure times. The amount of information which can be gleaned from a map is finite and influences the limited level of performance one can expect for a first time pass through the actual environment.

Army doctrine recognizes that terrain is not neutral. The terrain provides a distinct advantage to the side which recognizes its limitations and advantages and uses this knowledge in the planning and conduct of operations [FM10 93]. In the past, this knowledge is gained through constant exposure to the environment that provided the owner of the terrain with additional information which could only be learned from on sight observations. Depending on the individual, the acquisition of such knowledge takes days, weeks, months, or even years. With limited exposure, individuals may only gain route knowledge of their environment and may never gain survey knowledge depending on how much of the terrain they are exposed to.

A virtual environment has many of the same characteristics as the real world with the added advantage of being able to look at the environment in many ways that are physically impossible in the actual world. Users can view the terrain from any altitude and position which allows them to freely move from ego to excocetric views. However, a virtual world cannot represent all the actual trees, holes, rocks, and other extraneous items in the environment. Geometric models may not be able to keep up with changes in the environment such as new ditches, damaged or modified structures, or fallen trees, due to insufficient intelligence reports, last minute corrections, or hardware and software limitations. This prevents the virtual world from being completely accurate in its representation of an environment.

Taking into account the strengths and weaknesses of the media, a chart has been developed depicting a possible correlation between land navigation performance and exposure to the media (Figure 5.1). The lower left corner represents the expected performance of an individual with no prior knowledge of the environment, no navigational experience, and no navigational aids who is inserted into the environment and told to move from Point A to Point B. The upper right corner represents the optimal performance expected of an individual who has been exposed to the environment for an extended period of time, possibly years, who is asked to move from Point A to Point B with no navigational aids.

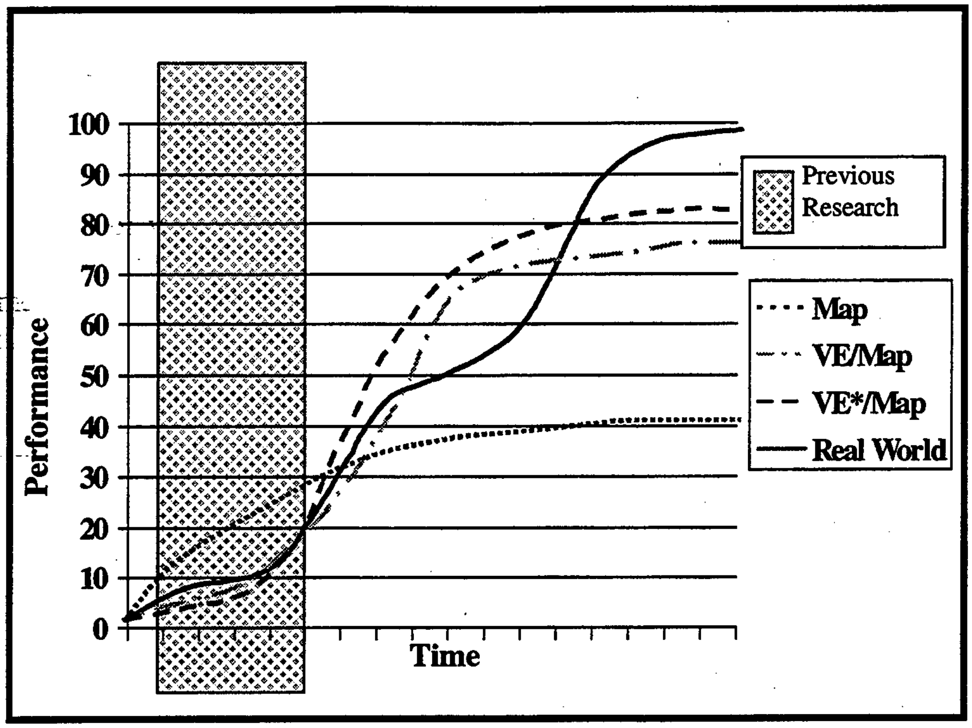


Figure 5.1. Performance Curves

The graph indicates an initial superior performance by those who are exposed to a map of the environment before insertion. This curve gives way to the high fidelity VE with map curve. The low fidelity VE with map curve initially outperforms the high-fidelity VE due to the additional time required by the high fidelity VE user to resolve differences and differentiate clutter from actual valid terrain features and landmarks. However, once these difference are resolved, the high fidelity VE outperforms the low fidelity VE curve due to the additional information it can provide. The real world curve initially outperforms the VE curves because less time is lost resolving differences in mental maps. The VE curves soon pass the real world curves due to the ability to compress training times in a VE and to gain both egocentric and excocentric views of the environment using the VE. The real world curve plateaus as the user becomes roughly familiar with the environment but still has not transitioned into a state of survey knowledge of his environment. Once an individual makes the transformation to survey knowledge in the real world, the real world curve begins to climb and soon surpasses the VE curves in performance. The optimal expected performance of the real world over the

VE is credited to the VE's inability to represent all the aspects of the real world. Most research in this area has been to the far left side of the time line. Further research is needed to validate the graph and curves to determine what the general values would be for the time scale and expected general navigational performance levels.

10. Navigation from Sea to Shore

Research has been conducted to identify participant abilities to navigate an open water virtual environment [DARK 95], a non real-time natural virtual environment [BANK 97], an overland helicopter virtual environment [SULL 98], and a real time natural virtual environment. However, no research has been conducted to test the validity of using a VE to train individuals to conduct from the sea navigation. From the sea navigation consists of approaching land from the open ocean or sea and conducting a mission on or over the land. This type of navigation requires the individual to transition from navigating open waterways to conducting appropriate navigation over land (flying) or on land (driving or walking). One of the most difficult tasks in this type of navigation is properly identifying terrain features while on the open water to use as guides for transition to navigation on land.

This type of navigation is routinely done by sailors and fishermen coming into ports or beach heads, Navy helicopter pilots conducting rescue missions of downed pilots, and by Navy Seals and Special Forces Teams who are infiltrating enemy territory from the sea. Reducing the chances of misinterpreting a proper land site or transition point can reduce parallel navigational errors, reduce mission execution times, and increase the chance for overall mission success.

11. Mandatory Map Checks at Each Control Point

One strategy used to help overcome short-term memory issues was to make a map check at each Control Point. One participant used this technique, M3. By conducting these checks, the participant verified his position within the world and was able to quickly memorize the route to the next control point.

Another issue is the reason people make map checks. Map checks can be broken down into two basic categories, maintenance checks and recover checks (Appendix Q, Figure Q.1). Maintenance checks are conducted to verify or confirm an individual's position, orientation, or route. A recover check is performed to determine an individual's

position, orientation, and plan a new route to return to the desired location. The difference for why an individual makes a map check drastically impacts on the amount and usefulness of information they extract during the check. Individuals, who are completely bewildered by the environment, can look at a map for minutes without resolving any of the issues and can confuse themselves even more. While individuals who know exactly where they are in the world and on the map can quickly verify their planned route, make modifications, and resolve any discrepancies in their mental maps.

Future studies should classify the type of checks an individual is performing to better understand how much the individual actual understands the terrain. The short term memory issue can be resolved by requiring each participant to conduct a fifteen second map check at each Control Point. Care must be taken to ensure the mandatory map checks do not turn the experiment into a map reading exercise. The question of map check classification can be resolved by asking the individual to tell the experiment monitor why they are making a map check. If participants indicate that they are verifying their location or route, the check is classified as a maintenance check. If participants indicate they are lost, trying to fix their position or planning a new route, then they are performing a recover check.

12. Orienteering Map vs 1:50,000 Map

Previously we discussed how the fidelity of the map may have played a major role in the performance of the Map Group Participants (Chapter 4.B.9). It is true that most military navigation is performed on a 1:50,000 (Appendix F, Figure F.1) or 1:24,000 (Appendix F, Figure F.2) map with rough sketches, blue prints, or aerial photos of the target areas. Most military personnel would never be afforded such a high resolution map depicting most linear features and categorizing the terrain to the degree that the experiment's 1:5,000 map provided. A more realistic study may use the 1:24,000 map in conjunction with an aerial photo and sketches of the control point areas instead of the high fidelity orienteering map. Participants could then draw their proposed route on an 8.5x11 inch aerial photo of the terrain. This would provide research monitors with the same resolution map to track and evaluate participant movement without providing a map with such a high degree of fidelity. This could also help to reduce problems with resolving distances for participants who are accustomed with standard military map

distances. Figure 5.2 shows the potential performance levels of individuals using

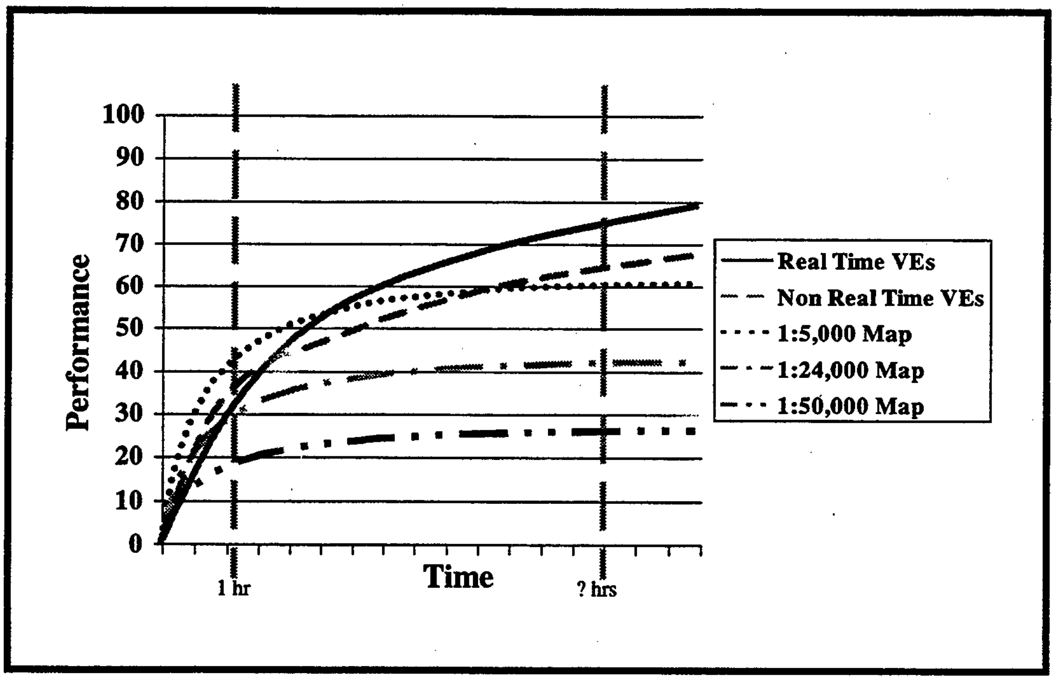


Figure 5.2. Medium Resolution vs Performance Diagram

differing training media. The performance curves for real time VEs, non real time VEs, and 1:5,000 scale map participants at the one-hour exposure mark are based on the results of the Banker experiment [BANK 97] and this thesis. The 1:24,000 and 1:50,000 scale map curves at the one-hour mark are predicted results. The optimal exposure times in each medium before performance levels off have not been verified through research. These times will vary based on the complexity of the environment and the abilities of the individual navigators.

13. Run Route Backwards

To reduce the memorization requirements and the length of the course, participants could be asked to plan and study a route that had only five or six controls. To increase the difficulty in the execution of the course while reducing the distance to be covered, the participants could then be asked to run the course in reverse order. For example, participants would be asked to plan a route through the control points in alphabetical order (A, B, C, D, E). When the participants are taken to the course, they are then informed they will run the course in reverse order (E, D, C, B, A).

This will allow participants in the VE and Real World Groups to have plenty of time to complete the course one or more times. It will also test to see if participants can play their mental movies or traverse their list of mental directions in reverse order. This would help to indicate that survey knowledge is being gleaned from the training phase and not merely route knowledge.

14. Introduction of Secondary Task

For most military missions, navigation is not the primary task. Instead it is a secondary task to get an individual or group of individuals to a location so that the primary task can be accomplished. Furthermore, during most military navigation operations, the task shares focus with the need to provide security and communicate with other entities. During this experiment, participants were asked to concentrate on navigating through the course as their primary task. At no time was an individual required to conduct more than one-task simultaneously during the execution phase of the experiment.

To provide more validity to the experiment, it would be prudent to quantitatively show that after training in a VE, individual navigation performance improved in the real world environment while secondary tasks are being performed. The secondary task would need to be simplistic in design to ensure additional training is not required to perform the task. At the same time, it must be complicated enough to require mental resources to be concentrated on the task for its successful completion.

15. Compare Execution Through VE and Real World

To better determine if a virtual world can substitute for its real world counterpart, an experiment testing navigation performance in a virtual world compared to navigation performance in the real world may provide some further insight. Both groups would be provided with the same training materials to plan a route through a course. Next, the participants would execute their planned routes through the actual navigation course or through a VE of the course. Measurements could then be taken on errors, distance per error, map checks, Wheel Tests, and Whiteboard Tests to determine if the two groups perform at relatively similar levels. This would help to ascertain if VEs are a viable substitute to a full-scale mock-up of the actual terrain.

APPENDIX A. EXPERIMENT OUTLINE

1) In Brief/Consent Form

    a) Time – 5 Min
    b) Location – CS Student Conf Room
    c) OIC – CPT Simon R. Goerger
    d) Materials – Consent Form, Privacy Act Statement, Minimal Risk Consent Form, Subject Roster, pencils, Fort Ord Map (confirm the subject has not been on the course terrain before), In Briefing Script

2) Color Blindness Test/Self Evaluation Questionnaires/Map Reading Test

    a) Time – 15 Min
    b) Location – CS Student Conf Room
    c) OIC – CPT Simon R. Goerger
    d) Materials – Color Charts (1 min), Self Ability Evaluation Sheet (1 min), Santa Barbara Sense of Direction Scale Questionnaire (3 min), Map Reading Test (5 min), pencil
    e) Grading (5 min)

3) Spatial Orientation

    a) Time – 15 Min
    b) Location – CS Student Conf Room
    c) OIC – CPT Simon R. Goerger
    d) Materials – Guilford-Zimmerman Aptitude Tests (10 min), pencils, answer sheets,
    e) Grading and Grouping (5 min)
    f) Groups

        i) Group A - Upper 50 percentile
        ii) Group B - Lower 50 percentile

4) Interface Familiarization (VE Only)

    a) Time – 15 Min minimum
    b) Location – Graphics Lab
    c) OIC – CPT Simon R. Goerger
    d) Materials –SGI machine, Performer Town Model, Flybox instructions, Virtual Environment Briefing Script, Interface Familiarization Checklist
    e) Movement (15 min minimum)

5) Training

a) Map Group

(1) Time – 60 Min
(2) Location – CS Student Conf Room
(3) OIC – CPT Simon R. Goerger
(4) Materials – Fort Ord Orienteering Map, Participant Task List, Map Marking Instructions, red alcohol marker, alcohol marker eraser, pencil, scratch paper, orienteering clue sheet, Map Group Briefing Script, Training Evaluation Sheet

b) Real World Group

(1) Time – 60 Min
(2) Location – Fort Ord Orienteering Course
(3) OIC – CPT Simon R. Goerger
(4) Materials – Fort Ord Orienteering Course, Fort Ord Orienteering Map, Participant Task List, Map Marking Instructions, red alcohol marker, alcohol marker eraser, pencil, scratch paper, orienteering clue sheet, compass, Real World Group Briefing Script, Training Evaluation Sheet

c) Virtual Environment Group

(1) Time – 60 Min
(2) Location – Graphics Lab CPT Simon R. Goerger
(3) OIC – CPT Simon R. Goerger
(4) Materials – Elvis. (SGI) w/ flybox and 21"/40" screen configuration or projector, Fort Ord Model, Fort Ord Orienteering Map, Participant Task List, Map Marking Instructions, Flybox instructions, red alcohol marker, alcohol marker eraser, pencil, scratch paper, orienteering clue sheet, Virtual Environment Briefing Script, Training Evaluation Sheet

6) Testing (est Time 120 Minutes – travel to Fort Ord Orienteering Course, run the course, and return).

a) Time – Travel Time 30 Min (total); Run Course 90 Min; Total Time (120 min)
b) Location – Fort Ord Orienteering Course
c) OIC – CPT Simon R. Goerger

d) Materials – Clipboard with subject's map & designated route, compass, Think Out Loud Instructions, Data Collection Sheet, red pen to record data, blue alcohol pen, stop watch/timer, Color Wheel for Tasks 3.1. & 5.1, White Board with ten magnets, rucksack frame w/GPS system, helmet & camera, water, first aid kit (cellular phone), Course Briefing Script, blind fold (for movement to course), spare clue sheet & color wheel arrows, Tecnu (for poison oak)

e) Tasks:

i) Task 1. (*Path Knowledge*) Move from the starting point to Checkpoint #1 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

ii) Task 2. (*Path Knowledge*) Move from Checkpoint #1 to Checkpoint #2 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

iii) Task 3.1. (*Survey Knowledge*) Take bearings to SP, CP #5, and CP #9 at the south side of CP #4)

iv) Task 3.2. (*Path Knowledge*) Move from Checkpoint #2 to Checkpoint #3 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

v) Task 4. (*Path Knowledge*) Move from Checkpoint #3 to Checkpoint #4 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

vi) Task 5.1. (*Survey Knowledge*) Take bearings to CP #1, CP #6, and CP #8 at the south side of CP #4)

vii) Task 5.2. (*Path Knowledge*) Move from Checkpoint #4 to Checkpoint #5 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

viii) Task6. (*Path Knowledge*) Move from Checkpoint #5 to Checkpoint #6 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

ix) Task 7. (*Path Knowledge*) Move from Checkpoint #6 to Checkpoint #7 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

x) Task 8. (*Path Knowledge*) Move from Checkpoint #7 to Checkpoint #8 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

xi) Task 9. (*Path Knowledge*) Move from Checkpoint #8 to Checkpoint #9 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

xii) Task 10. (*Survey Knowledge*) Have subject indicate bearing and route he must traverse to make it to Checkpoint #4. Have subject return to Checkpoint #4. (mark route and any turn which leads the subject away from Checkpoint #4. Allow a maximum of ten minutes to return to Checkpoint #4)

xiii) Task 11. (*Survey Knowledge*) Have subject arrange magnets on the white board indicating the location of the starting point and nine checkpoints. Measure time and note method of magnet placement (i.e. in order of visit, outside-in, or inside-out). Take picture of final results (allow 5 minutes maximum).

g) Error (Definition)

Subject strays from designated route (5 meters from designated route on a path/trail/road; 15 meters from cross country designated route). (record one error)

7) Debriefing.

a) Time – 30 Min
b) Location – Graphics Lab
c) OIC – CPT Simon R. Goerger
d) Materials – Clipboard with subject's map & designated route, Data Collection Sheet, red pen to record data, GPS system, Troop (PC) w/ Arcview and Fort Ord Maps, digital camera, Participant Questionnaire(s), Researcher's Script
e) Administer questionnaire(s); down load GPS datum and display on aerial photo using Arcview.
f) Discuss route.

i) Have the subject complete the Debriefing Questionnaire. Read their answers and ask for any clarification.
ii) Walk the subject through his route using the subjects planned route and the GPS data down loaded from the Message Pad and plotted on the aerial photo in Arcview.

(a) Have the subject to explain why they deviated from their route at those locations where the two differ.
(b) Have the subject explain when & how they determined they were off course.
(c) Have the subject explain how they recovered.

iii) Ask the subject if he would have done anything different in the training phase now that has completed the experiment.
iv) How much time does the subject spend playing computer games or working with computer graphics (more than an hour a day, a couple hours a week, once or twice a month, rarely, never)?

APPENDIX B. TASK LISTING

Task 1. (*Path Knowledge*) Move from starting point to Checkpoint #1 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 2. (*Path Knowledge*) Move from Checkpoint #1 to Checkpoint #2 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 3.1. (*Survey Knowledge*) Take bearings to SP, CP #5, and CP #9 at the south side of CP #4).

Task 3.2. (*Path Knowledge*) Move from Checkpoint #2 to Checkpoint #3 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 4. (*Path Knowledge*) Move from Checkpoint #3 to Checkpoint #4 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 5.1. (*Survey Knowledge*) Take bearings to CP #1, CP #6, and CP #8 at the south side of CP #4).

Task 5.2. (*Path Knowledge*) Move from Checkpoint #4 to Checkpoint #5 along designated route (measure elapsed time and # errors; mark deviation from route on map).

Task 6. (*Path Knowledge*) Move from Checkpoint #5 to Checkpoint #6 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 7. (*Path Knowledge*) Move from Checkpoint #6 to Checkpoint #7 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 8. (*Path Knowledge*) Move from Checkpoint #7 to Checkpoint #8 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 9. (*Path Knowledge*) Move from Checkpoint #8 to Checkpoint #9 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 10. (*Survey Knowledge*) Have subject indicate bearing and route he must traverse to make it to Checkpoint #4. Have subject return to Checkpoint #4 (mark route and any turn which leads the subject away from Checkpoint #4. Allow a maximum of ten minutes to return to Checkpoint #4).

Task 11. (*Survey Knowledge*) Have subject arrange magnets on the white board indicating the location of the starting point and nine checkpoints. Measure time and note method of magnet placement (i.e. in order of visit, outside in, or inside out). Take picture of final results (allow 5 minutes maximum).

APPENDIX C. BRIEFING SCRIPTS

1. GENERAL

The scripts in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis format utilized in the chapters of this document. This appendix consists of five briefing scripts: In Briefing, Control Group Briefing, Map Group Briefing, Virtual Environment Briefing, and the Course Briefing. Each participant receives the In Briefing and Course Briefing. The participants are exposed to either the Control Group Briefing, Map Group Briefing, or Virtual Environment Briefing depending on which group they are assigned. This appendix also contains the Debriefing hand out.

2. IN BRIEFING

Welcome to the Naval Postgraduate School's Computer Science Department. My name is ____________. Thank you for your assistance with today's experiment. Today's experiment deals with dismounted navigation in natural terrain.

This experiment is not a test of your intelligence or performance. Rather, it is an evaluation of navigational tools. ***(For Military Personnel)*** *Your performance will not be recorded in your personnel records but is intended for research purposes only.* All information collected is for academic research only. Prior to starting the experiment you will be asked to read and sign a series of consent forms. Upon signing the consent forms, you will take self-evaluation, map reading, and spatial orientation exams. After the tests, you will under go a sixty-minute train-up period prior to moving to the navigation course. Upon completing the course, you will be brought back to Spanagel Hall for a short debriefing.

If there are no questions, please read and sign this consent form.

3. CONTROL GROUP BRIEFING

In front of you is a map of an orienteering course as well as the actual terrain depicted on the map. You also have a clue sheet describing the location of the control points and photos of the control points. The map, photos, and terrain are for your use to study and plan the route you will be using to navigate the course.

You have sixty minutes to study the map and terrain. Your planned route must navigate you through the nine checkpoints in order. ***(Show the participant the checkpoints in order then point out each checkpoint in the photo.)*** Beginning at the designated starting point, you will go to CP1, then to CP2, then to CP3, ... and finally to CP9. The checkpoints are described in the clue sheet provided. You may take the clue sheet with you when you go on the course. Before the end of the sixty-minute study phase, you will mark your planned route on the map using a red alcohol marker.

After completing the study phase, you will be escorted back to the starting point to run the route you designated on your laminated map. While navigating the course, you will not have the map nor will you be allowed to use a compass. During the execution of the course, you may request a thirty seconds map or compass check; or a sixty-second map and compass check. You can request as many map or compass checks as you wish, but each check will be recorded. If you decide to deviate from your previously planned route, you may request the map to mark your newly planned route.

Do you have any questions before we begin?

4. MAP GROUP BRIEFING

In front of you is a map of an orienteering course. You also have a clue sheet describing the location of the control points as well as photos of the control points. The map and photos are for your use to study and plan the route you will be using to navigate the course.

You have sixty minutes to study the map. Your planned route must navigate you through the nine checkpoints in order. ***(Show the participant the checkpoints in order then point out each checkpoint in the photo.)*** Beginning at the designated starting point, you will go to CP1, then to CP2, then to CP3, ... and finally to CP9. The checkpoints are described in the clue sheet provided. You may take the clue sheet with you when you go on the course. Before the end of the sixty-minute study phase, you will mark your planned route on the map using a red alcohol marker.

After completing the study phase, you will be taken to the navigation course to run the route you designated on your laminated map. While navigating the course, you will not have the map nor will you be allowed to use a compass. During the execution of the course, you may request a thirty seconds map or compass check; or a sixty-second map and compass check. You can request as many map or compass checks as you wish, but each check will be recorded. If you decide to deviate from your previously planned route, you may request the map to mark your newly planned route.

Do you have any questions before we begin?

5. VIRTUAL ENVIRONMENT GROUP BRIEFING

Prior to beginning the study phase you will under go a fifteen-minute model familiarization phase. This is to help you become comfortable with the model controls prior to starting the experiment. The model you will be using for this phase bears no resemblance to the actual model to be used during the training phase. You will be required to show proficiency with the interface prior to moving on to the terrain model.

In front of you are the 3-screen configuration, a joystick interface, and a list of instructions for the use of the interface *(demo controls)*. Please feel free to explore the environment and controls for the next few minutes. When you feel confident with the controls, I will walk you through a serious of questions to demonstrate your expertise.

(Conduct Familiarization Phase; after the participant demonstrates proficiency with the interface, load up the terrain model and begin the training phase)

In front of you is a map of an orienteering course as well as a high fidelity 3-D model of the terrain depicted on the map. You also have a clue sheet describing the location of the control points as well as photos and screen capture images of the control points. The map, photos, and VE are for your use to study and plan the route you will be using to navigate the course.

You have sixty minutes to study the map and VE. Your planned route must navigate you through the nine checkpoints in order. ***(Show the participant the checkpoints in order then point out each checkpoint in the photo.)*** Beginning at the designated starting point, you will go to CP1, then to CP2, then to CP3, ... and finally to CP9. The checkpoints are described in the clue sheet provided. You may take the clue sheet with you when you go on the course. Before the end of the sixty-minute study phase, you will mark your planned route on the map using a red alcohol marker.

After completing the training phase, you will be taken to the navigation course to run the route you designated on your laminated map. While navigating the course, you will not have the map nor will you be allowed to use a compass. During the execution of the course, you may request a thirty seconds map or compass check; or a sixty-second map and compass check. You can request as many map or compass checks as you wish, but each check will be recorded. If you decide to deviate from your previously planned route, you may request the map to mark your newly planned route.

Do you have any questions before we begin?

6. COURSE BRIEFING

Pick-up participant from the Graphics Lab.

Move participant to the Fort Ord orienteering course.

Move participant to start point:

Brief the participant on animals and ammunition

"You are at the start point of the Navigation Course. During the experiment, I may stop you and ask you to answer questions. You must navigate the nine checkpoints in order. Each control point will be identified by a control point marker ***(show participant a control marker)*** which you must touch prior to moving to the next control point. Once you touch a control marker, I will tell you which marker it is. If it is the correct marker, I will give you further instructions. If it is the incorrect marker, I will not say anything other then the marker's number. I will not stop you unless you attempt to cross the course boundaries ***(show participant the boundaries)***. You may request the compass for a thirty second compass check; the map for a thirty second map check; or the map and compass for a sixty second compass and map check. These checks will be recorded and timed by me. If you determine that you would like to change your route, you may request the map and a blue marker to mark changes to your proposed route. You will have sixty seconds to mark your new route. You may request an additional sixty seconds if you deem it necessary. You have sixty minutes to make it as far as you can along your planned route. From now until completion of the navigation course do not interact with **anyone**. Before you begin, do you have any questions?"

TASK 1: START POINT TO CHECKPOINT ONE.

Task: "Your first task is to move from the start point to checkpoint one along your designated route."

Condition: "Without a map or interaction with anyone move from start point to checkpoint one along your preplanned route. If you deviate from the designated route you will be allowed to continue your movement unless you attempt to go outside the course boundaries. You may deviate 5m from your route, if you are on a trail, or 15m, if you are conducting cross-country movement before you are assessed an error. You can move back and forth along your route without being assessed an error. If you deviate from your path for more then 15 continues minutes and are not make progress towards the intended control point, I will stop you, show you your location on the map, and give you sixty seconds to mark a new route to the appropriate control point."

Standard: "Do the best you can."

"Ready,... Begin."

TASK 2: CHECKPOINT ONE TO CHECKPOINT TWO.

Task: "Checkpoint one. Your next task is to move from the checkpoint one to checkpoint two along your planned route. Conditions and standards are unchanged."

TASK 3.1.A, B, C: SPATIAL AWARENESS TEST I.

Stop timer

Stop participant at spatial awareness test area.

"Checkpoint two. Stop, I am going to have you identify the direction to three checkpoints."

Place the color wheel platform in its base on the south side of checkpoint.

Task: "Identify the direction to the start point, checkpoint five, and checkpoint nine."

Show participant arrows as you state their names.

Condition: "Given a color coded, 360-degree wheel and three arrows, identify the direction to the start point, checkpoint five, and checkpoint nine by placing the appropriate arrow in the direction of its checkpoint."

Standard: "Unchanged."

Record the time it takes the participant to perform the Wheel task and the orientation of the participant (looking north, south, east, rotates in the direction of the arrows, etc). Once done, photo graph the wheel, remove wheel platform from its stand, and have participant continue to checkpoint three.

TASK 3.2: CHECKPOINT TWO TO CHECKPOINT THREE.

Task: "Your next task is to move from the checkpoint two to checkpoint three along your planned route. Conditions and standards are unchanged. Ready,... Begin."

Start timer

TASK 4: CHECKPOINT FOUR TO CHECKPOINT FIVE.

Task: "Checkpoint three. Your next task is to move from the checkpoint three to checkpoint four along your planned route. Conditions and standards are unchanged."

TASK 5.1.A, B, C: SPATIAL AWARENESS TEST I.

Stop timer

Stop participant at spatial awareness test area.

"Checkpoint four. Stop, I am going to have you identify the direction to three checkpoints."

Place the color wheel platform in its base on the south side of checkpoint.

Task: "Identify the direction to checkpoint one, checkpoint six, and checkpoint eight."

Show participant arrows as you state their names.

Condition: "Given a color coded, 360-degree wheel and three arrows, identify the direction to checkpoints one, six, and eight by placing the appropriate arrow in the direction of its checkpoint."

Standard: "Unchanged."

Record the time it takes the participant to perform the Wheel task and the orientation of the participant (looking north, south, east, rotates in the direction of the arrows, etc). Once done, photo graph the wheel, remove wheel platform from its stand, and have participant continue to checkpoint five.

TASK 5.2: CHECKPOINT TWO TO CHECKPOINT THREE.

Task: "Your next task is to move from the checkpoint four to checkpoint five along your planned route. Conditions and standards are unchanged. Ready,... Begin."

Start timer

TASK 6: CHECKPOINT FIVE TO CHECKPOINT SIX.

Task: "Checkpoint five. Your next task is to move from the checkpoint five to checkpoint six along your planned route. Conditions and standards are unchanged."

TASK 7: CHECKPOINT SIX TO CHECKPOINT SEVEN.

Task: "Checkpoint six. Your next task is to move from the checkpoint six to checkpoint seven along your planned route. Conditions and standards are unchanged."

TASK 8: CHECKPOINT SEVEN TO CHECKPOINT EIGHT.

Task: "Checkpoint seven. Your next task is to move from the checkpoint seven to checkpoint eight along your planned route. Conditions and standards are unchanged."

TASK 9: CHECKPOINT EIGHT TO CHECKPOINT NINE.

Task: "Checkpoint eight. Your next task is to move from the checkpoint eight to checkpoint nine along your planned route. Conditions and standards are unchanged."

TASK 10.1: CHECKPOINT 4 IDENTIFICATION.

While standing at checkpoint nine:

Stop timer

Task: "Checkpoint nine, finish point. Your next task is to identify the location of checkpoint four from where you are."

Condition: "Point to checkpoint four and tell me where checkpoint four is from here. (i.e., twenty meters and in this direction)."

Standard: "Unchanged."

TASK 10.2: DESCRIBE ROUTE FROM CHECKPOINT NINE TO START POINT

Task: "Your next task is to describe what you consider the easiest route you would take to move from here to checkpoint four."

Condition: "Without a map, describe the route you would take to move from checkpoint nine to checkpoint four."

Standard: "Unchanged."

TASK 10.3: CHECKPOINT NINE TO START POINT (if described route would take them in the general location of the start point)

Task: "Your next task is to move from checkpoint nine to checkpoint four using the route you just described."

Condition: "Again, do not interact with anyone to include the researcher. You may not request a map or a compass check."

Standard: "You have ten minutes, otherwise standards are unchanged."

"Ready,... Begin"

Start timer

Reach checkpoint #4 or ten minutes has elapsed.

FINISH

Stop timer

"Stop. Congratulations you have completed the navigation portion of this experiment. We will now return to the vehicle for one final test before returning to the laboratory."

TASK 11: WHITE BOARD TEST.

Task: "Your final task is to create a top down representation of the start point and nine control points."

Condition: "Without a map or interaction with anyone take the ten magnets labeled with the start point and nine checkpoints ***(show the participant the magnets)*** and place them on a clean white board in proper perspective to each other. You are attempting to create a top down view of the checkpoints, actual distance between points does not matter, however, relative locations to each checkpoint does. Until you feel you are finished or five minutes has elapsed, you may place and move the magnets as you wish.

Standard: "Do the best you can."

"Any questions,... Ready,... Begin."

Start timer

Stop the timer when the participant indicates he has finished or ten minutes has elapsed, which ever occurs first. Observe the participant and note his method for placing the magnets (i.e. in order of visit, outside in, or inside out). Take a picture of the final results (allow participant 5 minutes maximum to perform the task).

Stop timer

"Stop. Congratulations on completing the final task for this experiment. We will now return to NPS for a final debriefing session."

Move participant back to the Graphics Lab for debriefing.

7. DEBRIEFING

The use of virtual environments in training and education has been an expanding field for the last two decades. With recent developments in computer systems, virtual reality models are now able to display much higher fidelity. In order to insure we are providing a positive training transfer and properly replicating real world environments, research is being conducted in the levels of detail required in models.

The study you have just completed is concerned with gathering information on how individuals navigate through complex virtual environments. You spent a session planning and studying a route demonstrating route knowledge. Finally, you demonstrated spatial knowledge of the terrain through estimating bearings to known points and movement to an unplanned location.

Three separate groups were examined in order to determine performance levels. All three groups were given an orienteering map on which they designated their routes prior to running the navigation course. The first group was only allowed to study the map for 60 minutes. The second group was given the map and allowed to move through the terrain for 60 minutes prior to running the course. The third group was give the map and was allowed to maneuver through a real time, high fidelity virtual representation of the terrain for 60 minutes.

The research personnel observed and recorded information based on the experience and behavior of the participants in order to gather the information equipped for the redesign and implementation of a more useful virtual model. The notes and observations collected will be used for the purpose of establishing standards for model development.

Your assistance in this project will contribute to the production of more useful virtual environments that provide users with spatial knowledge and better navigational skills. With the information gathered from your experience and the experience of other participants, we are discovering what people generally use as navigational cues in the virtual and real world environments. This information will assist in the design of future virtual reality models that will be adaptive to a variety of individual needs.

If you have any questions about the study, please ask your research assistant. *Until 30 July 1998, please do not discuss this experiment with anyone except our research personnel to prevent influencing any future participants*. Thank you for your participation in this study.

The research supervisor, CPT Simon R. Goerger, for this study can be contacted at (408) 656 – 4077 or Email: srgoerge@cs.nps.navy.mil.

APPENDIX D. CONSENT FORMS

1. GENERAL

The forms in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis format utilized in the chapters of this document. This appendix consists of three documents: Consent Form, Minimal Risk Consent Statement, and the Privacy Act Statement. Each participant is required to read and sign these documents before he is allowed to participate in the study. A research monitor observes and verifies the signing of each document. The format and content of these documents is based on the forms used in MAJ William Banker's land navigation experiment [BANK 97].

2. CONSENT FORM

PARTICIPANT CONSENT FORM

1. **Introduction.** You are invited to participate in a study of spatial awareness of natural and virtual environments. With information gathered from you and other participants, we hope to discover insight on navigational aids used to move through virtual environments during dismounted navigation of natural terrain. We ask you to read and sign this form indicating that you agree to be in the study. Please ask any questions you may have before signing.

2. **Background Information.** The Naval Postgraduate School NPSNET Research Group is conducting this study.

3. **Procedures.** If you agree to participate in this study, the researcher will explain the tasks in detail. There will be two sessions: a) 30 pretest phase and 2) training and execution phases lasting approximately five hours in duration, during which you will be expected to accomplish a number of tasks related to navigating natural terrain.

4. **Risks and Benefits.** This research involves no risks or discomforts greater then those encountered in ordinary hike through rolling, wooded terrain. The benefits to the participants are gaining techniques for enhancing spatial knowledge of unfamiliar environments and contributing to current research in human-computer interaction.

5. **Compensation.** No tangible reward will be given. A copy of the results will be available to you at the conclusion of the experiment.

6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which will possibly identify you as a participant.

7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form for your records.

8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you may contact the research supervisor, CPT Simon R. Goerger, at (408) 656 – 4077 (Email: srgoerge@cs.nps.navy.mil).

9. **Statement of Consent.** I have read the above information. I have asked all question and have had my questions answered. I agree to participate in this study.

-- --------------------------

Participant's Signature Date

-- --------------------------

Researcher's Signature Date

3. MINIMAL RISK CONSENT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
MINIMAL RISK CONSENT STATEMENT

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN: Virtual Environments and Navigation in Natural Environments

1. I have read, understand and been provided "Information for Participants" that provides the details of the below acknowledgments.

2. I understand that this project involves research. An explanation of the purposes of the research, a description of procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

3. I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

4. I have been informed of any benefits to me or to others that may reasonably be expected from the research.

5. I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

6. I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

7. I understand that my participation in this project is voluntary, refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

8. I understand that the individual to contact should I need answers to pertinent questions about the research is Rudy Darken, Ph.D., Principal Investigator, and about my rights as a research participant or concerning a research related injury is the Modeling Virtual Environments and Simulations Chairman. A full and responsive discussion of the elements of this project and my consent has taken place.

Medical Monitor: Flight Surgeon, Naval Postgraduate School

____

Signature of Principal Investigator Date

____

Signature of Volunteer Date

____

Signature of Witness Date

4. PRIVACY ACT STATMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
PRIVACY ACT STATEMENT

1. Authority: Naval Instruction

2. Purpose: Spatial Cognition information will be collected to enhance knowledge, or to develop tests, procedures, and equipment to improve the development of Virtual Environments.

3. Use: Spatial Cognition information will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.

4. Disclosure/Confidentiality:

    a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number which thereafter will be the only identifying entry on any of the research records. The Principal Investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

    b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

    c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

____

Signature of Volunteer   Name, Grade/Rank (if applicable)   DOB   SSN   Date

____

Signature of Witness   Date

APPENDIX E. QUESTIONNAIRES AND TESTS

1. GENERAL

The items in the appendix appear in the same format utilized for the experiment and thus do not follow the standard thesis format utilized in the chapters of this document. This appendix consists of eight documents: Land Navigation Questionnaire, Self Ability Evaluation, Santa Barbara Sense-of-Direction Scale, Map Reading Test, Guilford-Zimmerman Aptitude Survey, Practice Model Test, and two Debriefing Questionnaires.

The Land Navigation Questionnaire (Appendix E.2) provides a very general background of the participant. The participant, prior to arriving to the experiment site, completes this questionnaire.

The Self Ability Evaluation (Appendix E.3) is a qualitative self analysis of an individual's navigational ability. It provides a participant with general limits from which to appraise his perceived navigation aptitude. The left end of the scale is valued at 0.00 and the right end of the bar line is valued at 1.00. Values measured from 0.00 to 0.33 are assessed as beginning navigators. From 0.33 to 0.66 is ranked as an intermediate navigator. Values of 0.66 to 1.00 are evaluated as experts.

The Santa Barbara Sense-of-Direction Scale (Appendix E.4) is a quantitative self-evaluation of navigational ability. The University of California at Santa Barbara developed the scale. An individual's score is calculated by reversing the values of questions 2, 6, 8, 10, 11, 12, 13, and 15. For example, is the participant answered question number two as "3", the question is given a numerical value of "5". Once the values for the above questions are reversed, sum the value of each question and divide the total by the number of questions answered. The lower the resulting score the more confidant an individual is in their navigational abilities. The University of California at Santa Barbara calculates scale's mean score of 3.54 with a standard deviation of 1.03. For this experiment, the mean score was 2.62 with a standard deviation of 0.57.

The Map Reading Test (Appendix E.5) is comprised of twenty questions dealing with terrain feature identification. The test is designed to determine if an individual can read the terrain features on a map and associate them to real world terrain features. The first fifteen questions relate to properly naming terrain features from 1:50,000 scale

military maps and an orienteering map. The last five questions dealt with associating images of terrain features to map depictions of terrain features. The answers for the test are listed in Table E.1. Each question is worth one point. If a participant misidentifies a linear terrain feature they receive 0.5 points for the question. For example if the terrain feature is a stream and the participant classifies it as a road, they receive 0.5 points for the question. However, if the participant describes a stream as a draw, they receive no credit. Participants must score 65% (13 out of 20) or better to be allowed to participate in the study. Scores ranged from 13 to 20 with a mean score of 87.5%.

Question	*Answer*	*Feature*
1.1	B	Draw
1.2	I	Spur/Finger
1.3	H	Saddle
1.4	A	Depression
1.5	C	Hill Top
2.1	F	Road/Trail
2.2	B	Draw
2.3	E	Ridge Line
2.4	L	Valley
2.5	I	Spur/Finger
3.1	I	Spur/Finger
3.2	C	Hill Top
3.3	G	Road/Trail Intersection
3.4	J	Stream/River
3.5	B	Draw
4.1	F	Road/Trail
4.2	D	Hill Top
4.3	A	Road
4.4	E	Saddle
4.5	C	Spur/Finger

Table E.1 Map Test Answer Key

The Guilford-Zimmerman Aptitude Survey (Appendix E.6) assesses an individual's spatial orientation ability. The results of this test are compared to a pool of national test scores to determine if a participant is above or below the national average

for spatial orientation. These results were used to determine which training phase a participant would undergo.

The Practice Model Test (Appendix E.7) is administered to each virtual environment participant prior to moving onto the actual course model. It is used to ensure that a participant understands and is able to implement the interface functions. Each virtual environment participant was required to complete each task of the Practice Model Test. After completing the test, a participant is retested on any functions they failed to properly employ until he is able to do so.

The Debriefing Questionnaires (Appendices E.8 and E.9) are administered prior to the final review of the participant's route. Participants in the Real World and Map Only Group received the questionnaire in Appendix E.8. Virtual Environment participants receive the questionnaire in Appendix E.9 that has an additional page containing questions related to the virtual environment and its interface. The questions are designed to provide a qualitative analysis of the training materials and course. A five point scale (1-5) is used for the questionnaire. The final page of the questionnaire is designed to discover those terrain features an individual deems are most needed in a virtual environment from which they are obtaining navigational information. One item is deliberately left off the list of possible water features to see if participants are paying close attention or simply checking items on the list. This feature is streams/rivers.

The raw scores from these tests and questionnaires are listed in Appendix O.

2. LAND NAVIGATION QUESTIONNAIRE

Name:______________________________ Age:_____ Sex:_____

Branch of Service: ___________________ Rank: ______________

1) Where did you first learn to navigate?

a) Scouting, Boys/Girls Club
b) Parents
c) Friend
d) ROTC/Academy
e) Basic Training
f) Officer Candidate School
g) Officers Basic Course
h) Other: ____________

2) How many years have you been Orienteering/Navigating?

a) less then a year
b) one year or more
c) two years or more
d) five years or more
e) ten years or more

3) At what level would you classify your navigating abilities?

a) Novice/Beginner
b) Intermediate/Average
c) Expert/Advanced

4) How many Land navigation or Orienteering courses have you done in the last year?

5) The land navigation course runs through varying degrees of vegetation and over rolling terrain. It will require you to negotiate a distance of no more than three miles in one hour. Do you have any physical disabilities that would prevent you from executing this task? Yes/No

3. SELF ABILITY EVALUATION

Participant ID: _______

The following bar line depicts the navigation ability evaluation of an average infantry officer with five years experience. The "X" indicates his ability level.

X

Knows how to read a map

Navigates with no errors; Rarely looks at map

Place an "X" on the line below were you feel your navigational abilities are at this time.

Knows how to read a map

Navigates with no errors; Rarely looks at map

4. SANTA BARBARA SENSE-OF-DIRECTION SCALE

Participant ID: __________ Date: ___________ SEX: F M AGE:____

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experience. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at directions.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for were I left things.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W)

   strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

(turn over and continue)

9. I am very good at reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

strongly agree 1 2 3 4 5 6 7 strongly disagree

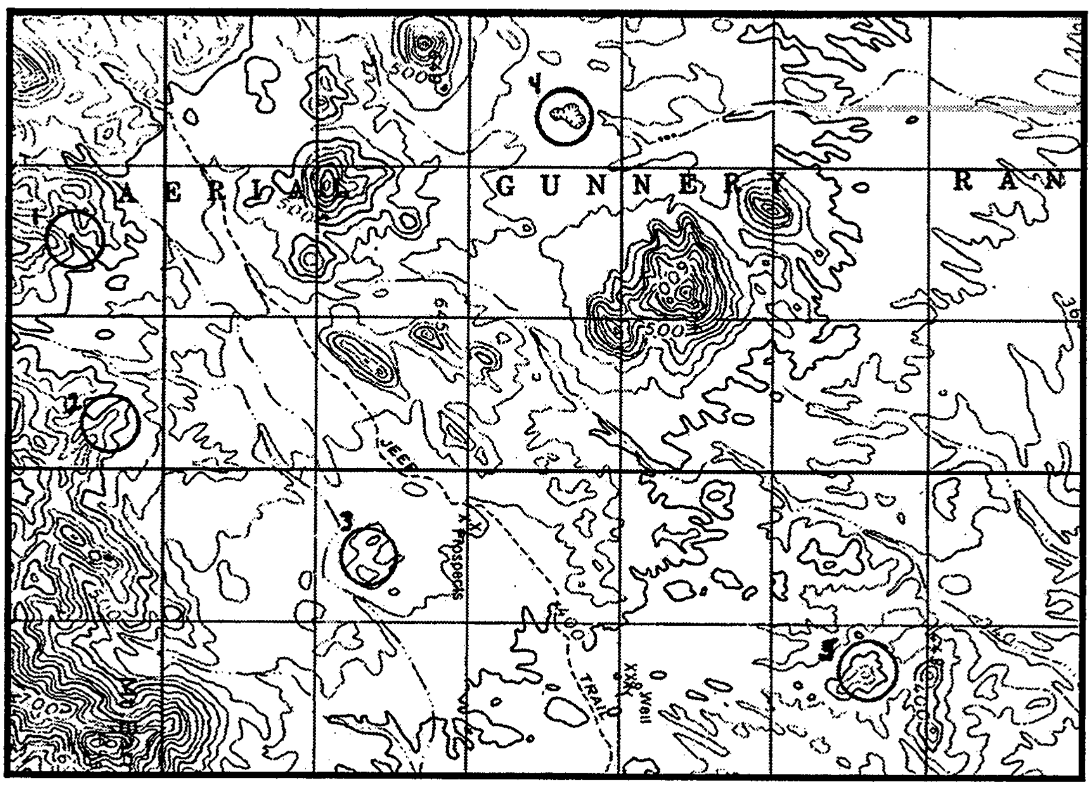
15. I don't have a very good "mental map" of my environment.

strongly agree 1 2 3 4 5 6 7 strongly disagree

5. MAP READING TEST

The following is a list of terrain features commonly found on military and/or orienteering maps. Using the list of terrain features, identify the most predominate terrain feature within each circle and place your answer in the space provided. Each terrain feature from the list may be used more than once or not at all.

A. Depression
B. Draw
C. Hill Top
D. Lake/Pond
E. Ridge Line
F. Road/Trail
G. Road/Trail Intersection
H. Saddle
I. Spur/Finger
J. Stream/River
K. Stream/River Intersection
L. Valley

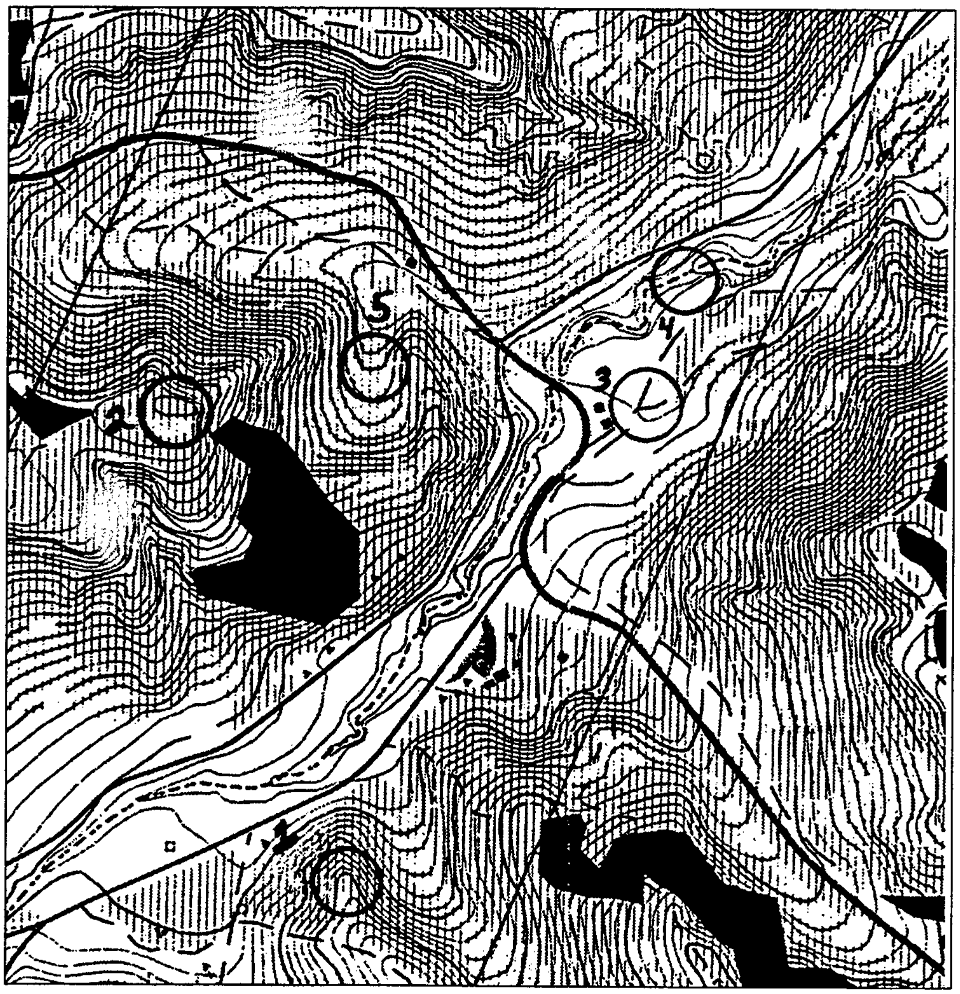


1. _____ 2. _____ 3. _____ 4. _____ 5. _____

A. Depression
B. Draw
C. Hill Top
D. Lake/Pond
E. Ridge Line
F. Road/Trail
G. Road/Trail Intersection
H. Saddle
I. Spur/Finger
J. Stream/River
K. Stream/River Intersection
L. Valley

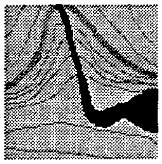
1. _____ 2. _____ 3. _____ 4. _____ 5. _____

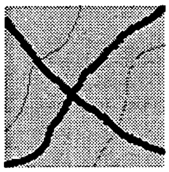
A. Depression
B. Draw
C. Hill Top
D. Lake/Pond
E. Ridge Line
F. Road/Trail
G. Road/Trail Intersection
H. Saddle
I. Spur/Finger
J. Stream/River
K. Stream/River Intersection
L. Valley

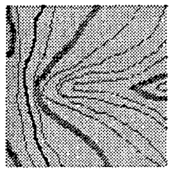


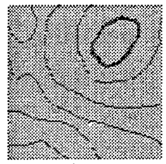
1. _____ 2. _____ 3. _____ 4. _____ 5. _____

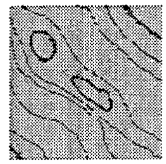
Using the following map representations, choose the best representation for each picture displayed below. The map representations are a facsimile of the terrain shown in the photos. Some map representations may be used more than once or not at all.

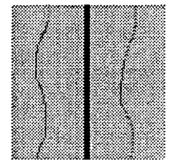

A


B

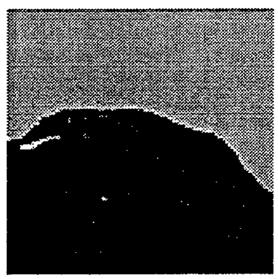

C

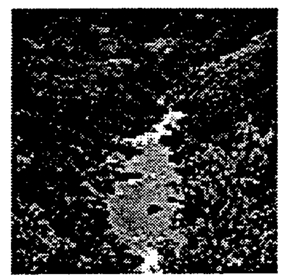

D


E


F


1. _____


2. _____


3. _____


4. _____


5. _____

6. GUILFORD-ZIMMERMAN APTITUDE SURVEY

The Guilford-Zimmerman Aptitude Survey

Part 5/Spatial Orientation

Name ______________________ Date ________ Score ________ Sex: M F

INSTRUCTIONS.

This is a test of your ability to see changes in direction and position. In each item you are to note how the position of the boat has changed in the second picture from the original position in the first picture.

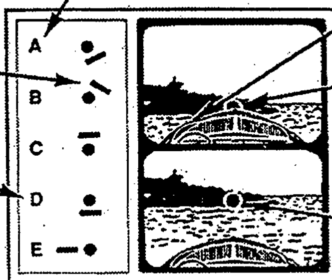
Here is Sample Item 1.

These are the five possible answers to the item.

These bars represent the boat's prow.

This is the correct answer. It shows that the prow of the boat has dropped below the aiming point.

(If the prow had risen, instead of dropped, the correct answer would have been C, instead of D.)



Sample Item 1

This is the prow (front end) of a motor boat in which you are riding.

This is the aiming point. It is the exact spot you would see on land if you sighted right over the point of the prow.

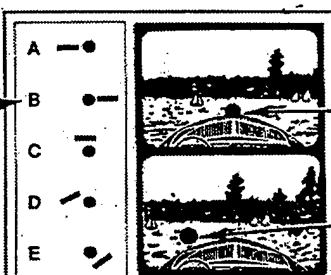
This is the same aiming point shown above. Note that the prow has dropped below it.

To work each item: **First**, look at the top picture and see where the motor boat is headed. **Second**, look at the bottom picture and note the CHANGE in the boat's heading. **Third**, mark the answer that shows the same change on the separate answer sheet.

Try Sample Item 2.

This also shows that the prow of the boat is to the right of the aiming point. So, it is the correct answer.

(If the boat had turned to the left, instead of to the right, the correct answer would have been A.)



Sample Item 2

This is the aiming point.

This is the same aiming point. The motor boat is now headed to the right of it.

Consulting Psychologists Press, Inc., 3803 E. Bayshore Road, Palo Alto, CA 94303 0039

98 97 96 95 94 8 7 6 5 4

Figure E.1 Guilford-Zimmerman Aptitude Survey Cover Page

7. PRACTICE MODEL TEST

a. Turn to a heading of 360 degrees and begin movement.

b. Switch to a top down view

c. Switch to a 15-meter view

d. Change to run mode

e. Change to walk mode

f. Move to the road and take a right

g. While following the road:

  i) Look-up
  ii) Look down
  iii) Look left
  iv) Look Right

h. Head into town

i. Stop

j. What is your heading?

k. Begin movement.

l. Run

m. Slow down and stop at the road sign

n. Look to your right. What do you see?

o. Using the quick view keys, see what is at CP6

p. Using the hot keys, return to the start point

8. DEBRIEFING QUESTIONNAIRES

a. Map and Real World Group Debriefing Questionnaire

MAP	Hard to Read				Easy to Read	
Was the map easy to read?	1	2	3	4	5	N/A
	Hard to Understand				Easy to Understand	
Was the map easy to understand?	1	2	3	4	5	N/A
Were the trails & roads adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Were the man made structures adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Were the obstacles adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Was the vegetation adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Using the map, how difficult was it to plan your route?	Easy				Very Difficult	
	1	2	3	4	5	N/A
Comments:						

COURSE	Easy				Very Challenging	
How difficult was the course?	1	2	3	4	5	N/A
	Definitely Not				Definitely Yes	
Were the control points well marked?	1	2	3	4	5	N/A
Were the control points located where you expected them?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Had routes been trampled down leading to the control points?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Did you have difficulties remembering your planned route?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Comments:						

MISC	Definitely Not				Definitely Yes	
Did you enjoy this experiment?	1	2	3	4	5	N/A
Did you feel the training phase was long enough?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Did you feel the training phase was too short?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Do you feel the training familiarized you learn the environment?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Did you feel confident in navigating the terrain without a map or compass?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Comments:						

1. Place an "X" next to the items you feel must be replicated in a model that prepares you to navigate an actual piece of terrain.

buildings	factory	______	roads	dirt roads	______
buildings	houses	______	roads	foot paths	______
buildings	public buildings	______	roads	paved roads	______
buildings	shacks	______	roads	trails	______
buildings	other	______	roads	other	______
misc	compass	______	obstacles	electric lines	______
misc	road signs	______	obstacles	pits/fox holes	______
misc	rock piles	______	obstacles	shallow ditches	______
misc	sand bags	______	obstacles	telephone poles	______
misc	street signs	______	obstacles	towers	______
misc	the sun	______	obstacles	trenches	______
misc	people	______	obstacles	other	______
misc	animals	______			
misc	sound	______			
misc	other	______	vegetation	bushes	______
misc	other	______	vegetation	flowers	______
			vegetation	grass/weeds	______
terrain	clearings	______	vegetation	trees	______
terrain	depressions	______	vegetation	other	______
terrain	hills	______			
terrain	knolls	______			
terrain	ridgelines	______	water	lakes	______
terrain	spurs/fingers	______	water	marsh lands	______
terrain	other	______	water	ponds	______
			water	puddles	______
			water	swamps	______
			water	other	______

2. From the list of items in question # 1, choose and rank the six items you feel are the most important for a computer model which will be used to prepare an individual to navigate an actual piece of terrain.

1 ______
2 ______
3 ______
4 ______
5 ______
6 ______

b. Virtual Environment Group Debriefing Questionnaire

MAP	Hard to Read				Easy to Read	
Was the map easy to read?	1	2	3	4	5	N/A
	Hard to Understand				Easy to Understand	
Was the map easy to understand?	1	2	3	4	5	N/A
Were the trails & roads adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Were the man made structures adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Were the obstacles adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Was the vegetation adequately shown on the map?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Using the map, how difficult was it to plan your route?	Easy				Very Difficult	
	1	2	3	4	5	N/A
Comments:						

COURSE	Easy				Very Challenging	
How difficult was the course?	1	2	3	4	5	N/A
	Definitely Not				Definitely Yes	
Were the control points well marked?	1	2	3	4	5	N/A
Were the control points located where you expected them?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Had routes been trampled down leading to the control points?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Did you have difficulties remembering your planned route?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Comments:						

MISC	Definitely Not				Definitely Yes	
Did you enjoy this experiment?	1	2	3	4	5	N/A
Did you feel the training phase was long enough?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Did you feel the training phase was too short?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Do you feel the training familiarized you learn the environment?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Did you feel confident in navigating the terrain without a map or compass?	Definitely Not				Definitely Yes	
	1	2	3	4	5	N/A
Comments:						

MODEL	Definitely Not				Definitely Yes	
Was the model clear and viewable?	1	2	3	4	5	N/A
Did the model coincide with the map?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Were the trails & roads adequately represented in the model?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Were the man made structures adequately represented in the model?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Were the obstacles adequately represented in the model?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Was the vegetation adequately represented in the model?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Were changes in elevation adequately represented in the model?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Did the model help you identify the control points within the last 50m?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Did the model help you identify the general area of the control points?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Using the model, how difficult was it to plan your route?	Easy 1	2	3	4	Very Difficult 5	N/A
Do you feel the model gave you an advantage you normally wouldn't have had?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Would you use this tool if it were available for mission planning?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Would you use this tool if it were available for mission rehearsal?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Would you use this tool if it were available for navigation training?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Comments:						

MODEL INTERFACE	Confusing				User Friendly	
Were you able to easily move through the model?	1	2	3	4	5	N/A
Was the joystick easy to use?	Confusing 1	2	3	4	User Friendly 5	N/A
Was the acceleration lever easy to use?	Confusing 1	2	3	4	User Friendly 5	N/A
Were the toggle buttons easy to use?	Confusing 1	2	3	4	User Friendly 5	N/A
Your overall felling about the interface?	Confusing 1	2	3	4	User Friendly 5	N/A
Was the 15-minute train-up on the initial model useful?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Was the 15-minute train-up on the initial model enough time to become familiar with the interface?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Did the use of three screens cause any confusion when maneuvering?	Definitely Not 1	2	3	4	Definitely Yes 5	N/A
Comments:						

1. Place an "X" next to the items you feel must be replicated in a model that prepares you to navigate an actual piece of terrain.

buildings	factory	________
buildings	houses	________
buildings	public buildings	________
buildings	shacks	________
buildings	other	________

roads	dirt roads	________
roads	foot paths	________
roads	paved roads	________
roads	trails	________
roads	other	________

misc	compass	________
misc	road signs	________
misc	rock piles	________
misc	sand bags	________
misc	street signs	________
misc	the sun	________
misc	people	________
misc	animals	________
misc	sound	________
misc	other	________
misc	other	________

obstacles	electric lines	________
obstacles	pits/fox holes	________
obstacles	shallow ditches	________
obstacles	telephone poles	________
obstacles	towers	________
obstacles	trenches	________
obstacles	other	________

vegetation	bushes	________
vegetation	flowers	________
vegetation	grass/weeds	________
vegetation	trees	________
vegetation	other	________

terrain	clearings	________
terrain	depressions	________
terrain	hills	________
terrain	knolls	________
terrain	ridgelines	________
terrain	spurs/fingers	________
terrain	other	________

water	lakes	________
water	marsh lands	________
water	ponds	________
water	puddles	________
water	swamps	________
water	other	________

2. From the list of items in question # 1, choose and rank the six items you feel are the most important for a computer model which will be used to prepare an individual to navigate an actual piece of terrain.

1 ________
2 ________
3 ________
4 ________
5 ________
6 ________

APPENDIX F. COURSE

1. GENERAL

This appendix consists of six items: 1:50,000 map excerpt of the course area, 1:24,000 map excerpt of the course area, an aerial photo of the course, an aerial photo with an example participant debriefing route, 1:5,000 course orienteering map, and an explanation of the map legend [BANK 97]. The 1:50,000 and 1:24,000 maps are the standard scales used by most US ground forces for military operations. Comparison with the course orienteering map show the magnitude of the additional information which can be gleaned from the orienteering map as compared to even the high resolution 1:24,000 military operations map. The aerial photo is the same one utilized by MAJ Banker to produce the original course map and was also used to display the participant's route during the debriefing phase of the experiment. The course map was modified from the original one developed by MAJ William Banker after field verification by CPT Simon Goerger. The map legend explanation is taken directly from Appendix D of MAJ Banker's 1997 Masters Thesis.

2. 1:50,000 MAP EXCERPT OF COURSE AREA

The center of Figure F.1 is the course area. The boundary roads and two north south trails are the only liner features that can be depicted on this map for the area. The high ground in the southwest corner of the course and the low ground on the east edge of the course are the only discernable terrain features. The entire course is depicted as being wooded. A 1:50,000 map of the Fort Ord training area was used to verify that a participant had not been in the target area in the past. Its lack of detail and the general overview it provided of the training area made it possible to identify locations where participants may have explored the old Fort Ord training area without furnishing participants additional information about the orienteering course.

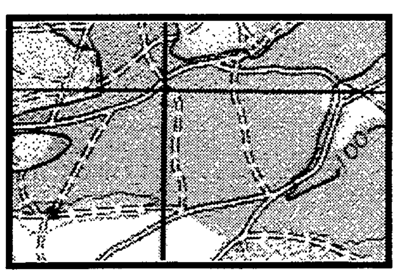


Figure F.1 1:50,000 Map Excerpt of Course Area (Actual Size)

3. 1:24,000 MAP EXCERPT OF COURSE AREA

The center of the Figure F.2 is the course area. The boundary roads and two north south trails are the only liner features that can be depicted on this map. The high grounds in the southwest corner and east of the course are discernable terrain features as well as the low ground on the east edge of the course and the northwest corner of the course. The entire course is depicted as being wooded.

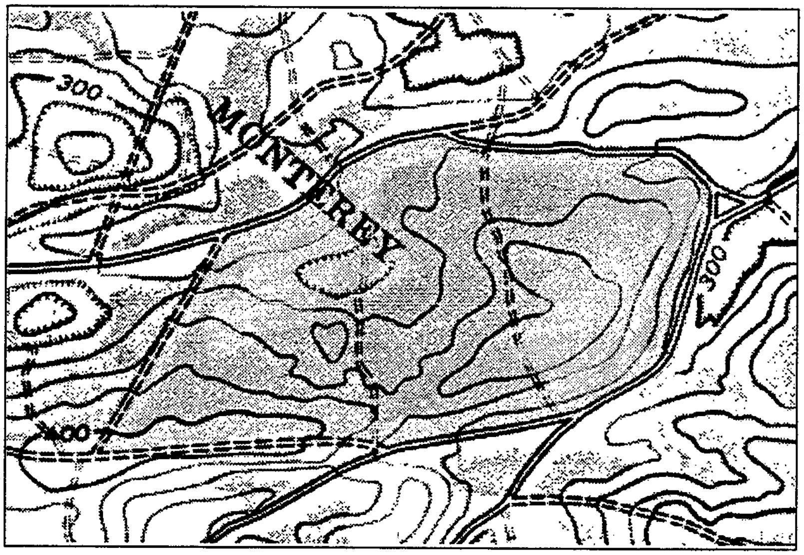


Figure F.2 1:24,000 Map Excerpt of Course Area (Actual Size)

4. AERIAL PHOTO

Figure F.3. Aerial Photo

5. AERIAL PHOTO WITH PARTICIPANT ROUTE

Figure F.4. Aerial Photo With Subject Route

6. COURSE MAP

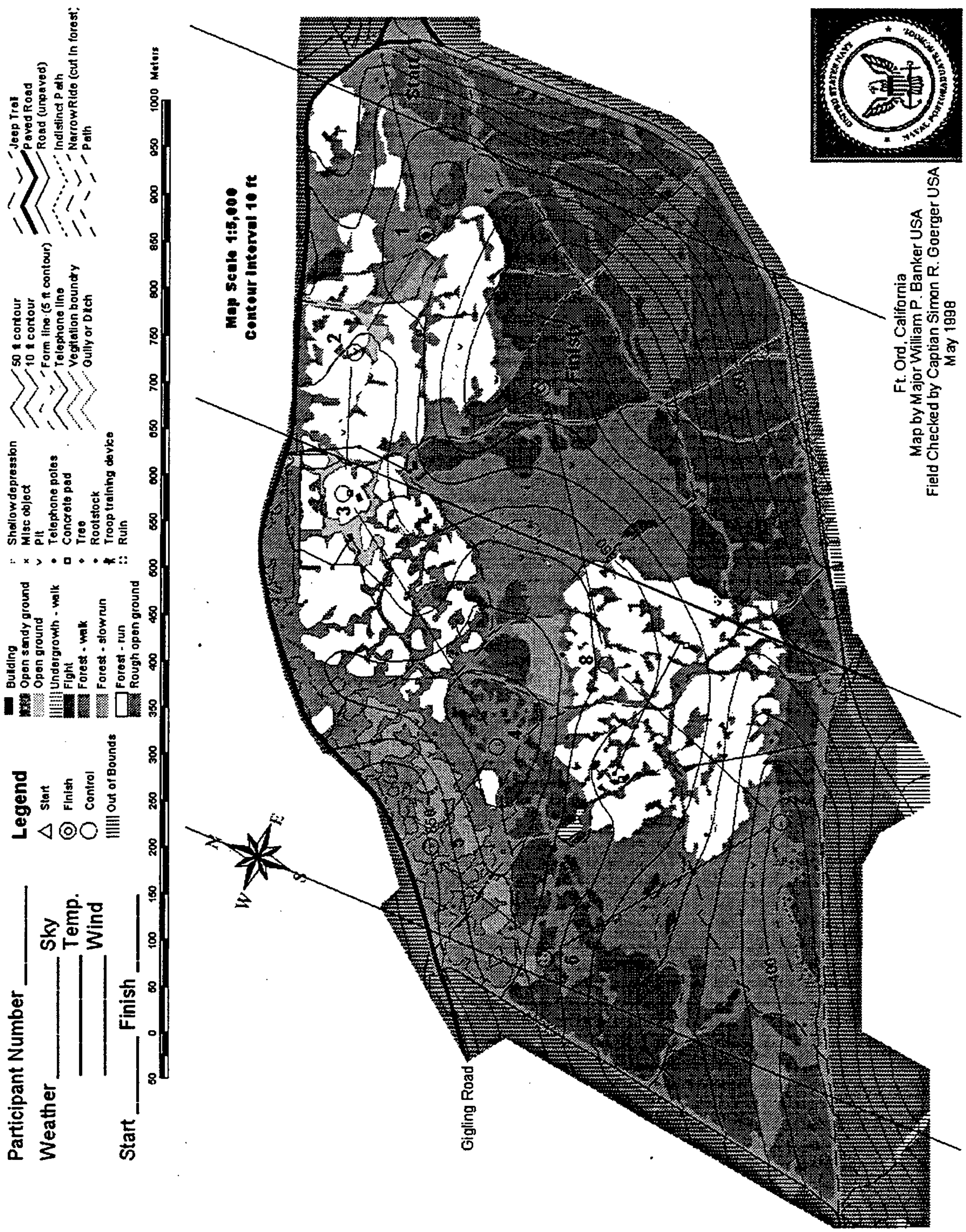


Figure F.3. Course Map

7. COURSE MAP LEGEND EXPLANATION

All maps are generalizations. They use symbols to portray actual features on the earth's surface. Not all features are represented with the same precision. Discrete non-vegetation items are plotted on the map in the exact location they are in the actual environment, whereas vegetation boundaries (unless indicated with a distinctive dotted line) are not meant to represent a clean break from one type of vegetation to another. Rather, this line separating one vegetation area from another is a generalization of where one type more or less ends and another more or less begins. The line separating the two can best be thought of as a blurry line where the two types of vegetation intermingle. The below guide will help to determine the specific limitations of each symbol on the orienteering map.

Building - Buildings in the area are of several types:

a. Latrines - most common building, tan in color, approx. size 3 x 8 meters

b. Shelters - second most common building, green wood, roofed, no walls, approx. size 3 x 8 meters

c. Admin. - field office and shack, black with gold trim, 8 x 8 meters and 2 x 2 meters respectively

Open Sandy Ground - a significant patch of sand that will slow running

Open ground - dirt, hard pack, free of grass and other vegetation.

Undergrowth walk - immature chaparral or oak, dense stands of bushes, incomplete overlap of two distinct areas of fight which allow restricted passage along that overlap, other plants that prevent running.

Fight - mature chaparral or immature oak in such density that passage through is very difficult, running impossible

Forest walk - oak forest with patchy undergrowth, low lying tree limbs or tree density that prevents running from being sustained

Forest slow run - oak forest fairly free of undergrowth, but with low lying limbs or tree density that makes sustained running difficult.

Rough open ground - grass covered ground, possibly with scattered (avoidable) undergrowth. Note that there are a few locations that have what appears to be old jeep trails but are portrayed as rough open ground. Sometimes the distinction between one or the other blurs. If in doubt refer to other more distinctive features (contour lines, etc.) to determine your location.

Shallow depression - most likely an old decaying foxhole position or other man made excavation where the banks have eroded to create a bowl-like depression of 1 to 3 feet below surrounding ground.

Misc. object - a manmade feature, rubble, derelict military equipment, or other item whose exact description is only provided if it is the location of a control

Pit - an old foxhole or likely other man made pit that has steep vertical walls and may be reinforced with wood, depth from 2 to 5 feet. Note that there will be many pits in the area that are not depicted on the map. The pits that are depicted are accurate.

Telephone poles - wood poles (if bearing wire it will be noted on map) approx. 25 to 30 feet in height

Concrete pad - old concrete tent pad extending from 2 to 5 inches above ground level

Tree - a tree or large bush (could be two or more trees growing close together – forming an unbroken single canopy -- if the trees are small)

Rootstock - a dead or overturned tree

Troop training device - a bunker or other man made item built for training soldiers

Vegetation boundary - the edge of a vegetation type

Gully or Ditch - ranging from a shallow 1-foot deep gully to 5-foot deep military trench

Jeep Trail - a road more suitable for 4 x 4 vehicles due to width restriction and/or ruts. May be distinctive and worn or in some places overgrown with grass but still containing ruts.

Paved Road - a surfaced all weather road

Road - a sandy or dirt road wide and level enough for 2 wheel drive vehicles

Indistinct Path - a path that is in the process of being overgrown with only intermittent marks on the ground that indicate that it was once a well traveled path

Narrow Ride - a linear break in the forest that may have once been a jeep trail but now is overgrown with grass and lacks telltale wheel ruts

Path - a foot or bike path.

APPENDIX G. PARTICIPANT TASK LIST[1]

Thank-you for participating in this study. You will do an Orienteering course today. However, there are some important differences to note:

1. You will be wearing a light pack with DGPS and Newton MSG Pad 130. Its purpose is to log your route and act as a data capture device for other actions you may perform.

2. Before you run the course you will carefully plan your route through the entire course (see Important Information on Marking Your Map)

3. Use this training time to commit the route and course to memory. You are expected to do the following on the actual course run:

   a. Navigate without aid of map and compass, utilizing only your memory
   b. Attempt to find all the controls utilizing your planned route

Summary of objectives

All Objectives are equally important!!

1. Choose the most efficient route based on your abilities
2. Minimize the number of map checks you request from the administrator
3. Minimize the number of compass checks you request from the administrator
4. Minimize the number of map with compass checks you request from the administrator
5. Stay on your planned route
6. Find all the controls in order (you have 60 minutes to conduct this task)

- If you need to make a map check then say so and the administrator will give you the map for 30 seconds. Additional time can be requested in 30 second increments at the additional cost of a map check each.
- If you need to make a compass check then say so and the administrator will give you the compass for 30 seconds. Additional time can be requested in 30 second increments at the additional cost of a compass check each.
- If you need both map and compass then say so and the administrator will give you both for 60 seconds. Additional time can be requested in increments of 60 seconds.
- If you want to change your route announce to the administrator that you are changing your route plan. At that point the administrator will hand you the map, compass, and blue pen. From the time that he gives you the materials you will have 30 seconds to plot the new route. If you need more time then tell him you need more time and you will get another 30 seconds. Request additional time as needed but remember that one of your objectives is to make as few map checks as necessary. **Every 30 seconds that you are looking at the map beyond the original 30 seconds for the route change counts as a map check.**

[1] This document is adapted and modified from MAJ Banker's Masters Thesis [BANK 98]

APPENDIX H. MAP MARKING INSTRUCTIONS[1]

Pay close attention to how you mark your route, be as precise as the map and pen allow. Before your actual run you are expected to preview your map within your group's prescribed context. Mark your **planned route using the RED pen**. You may correct any mistakes you make while planning with the white eraser. Once the planning period is up or you elect to finish you will not be allowed to erase any of the red route marks you have made. **SO BE PRECISE** in marking your map, detail does matter. Later during the actual course run anytime that you are going to deviate from your planned route you must stop:

1. Announce to the administrator that you are changing your route plan. At that point the administrator will hand you the map. From the time that he gives you the map you will have 30 seconds to plot the new route. If you need more time than tell him you need more time and you will get another 30 seconds. Request additional time as needed but remember that one of your objectives is to make as few map checks as necessary. **Every 30 seconds that you are looking at the map beyond the original 30 seconds for the route change counts as a map check.**

2. Take the blue pen and draw in your new route with the same attention to detail that you applied or the original route planning in red.

3. Leave your original route on the map. The eraser is provided so that you may make corrections to a route as you draw it. Once you finish drawing and begin navigating you are not allowed to erase routes, or corrections to planned routes (blue penned routes).

4. You may make as many corrections to your route(s) as necessary while navigating the course.

Importance of detail in map marking and navigation

You are allowed to deviate from your planned route within the following tolerances while still being considered on that route:

Jeep Trails, Paved Roads, Unpaved Roads, Indistinct Paths, Narrow Rides and Paths -- If your marked route is on any of these features you are allowed **5 meters either side** of the feature and you are still considered as being "on your route".

All other features -- On all other types of non road/trail terrain you may travel **15 meters to either side** of your marked route and you are still considered as being "on your route"

[1]This document is adapted and modified from MAJ Banker's Masters Thesis [BANK 98]

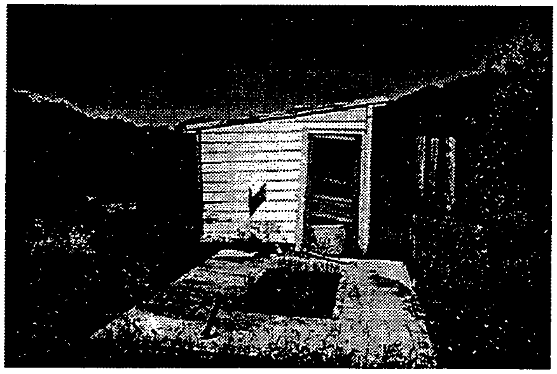
APPENDIX I. DIGITAL PHOTOS

1. GENERAL

Subjects are provided with a series of digital images of the control points. Map and Real World subjects receive the photos displayed in Appendix I.2 while Virtual Environment subjects receive the Appendix I.3 photo sets. The photos are furnished in color. The photos help to outfit the subject with a stronger grasp of the defining landmarks they are searching for. Under conditions that would allow the production of such a detailed map of the area, it is feasible to expect that reconnaissance photos would be available of these locations.

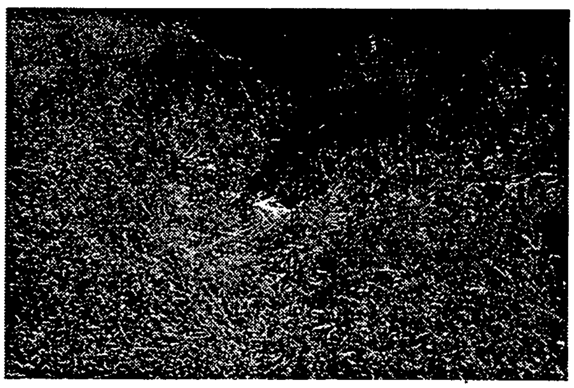
The VE participants are also presented with screen capture images of the Control Points from the same general direction and distance as the actual photos were taken. This provides the VE participants with additional information to assist them in resolving the differences between the VE and the real world.

2. MAP AND REAL WORLD GROUP PHOTOS



Control Point 1

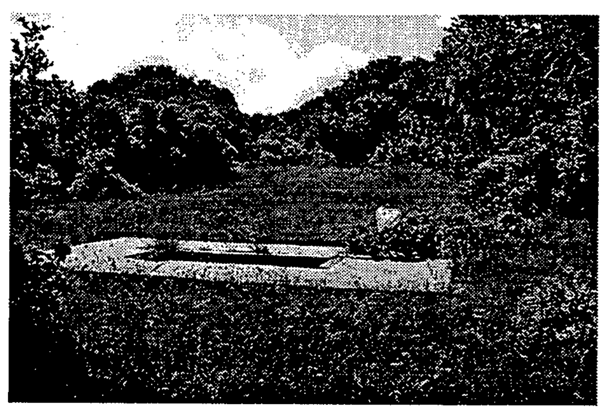
Control Point 4



Control Point 2

Control Point 5

Control Point 3



Control Point 6

Control Point 7

Control Point 8

Control Point 9

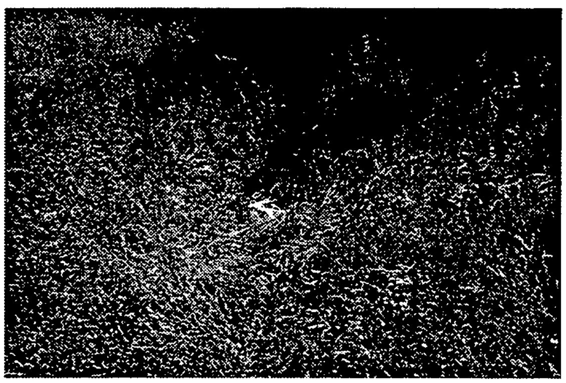
3. VIRTUAL ENVIRONMENT GROUP PHOTOS

Real World

Model

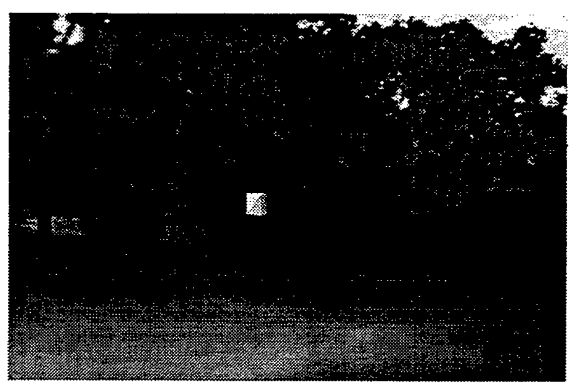
Control Point 1

Control Point 1



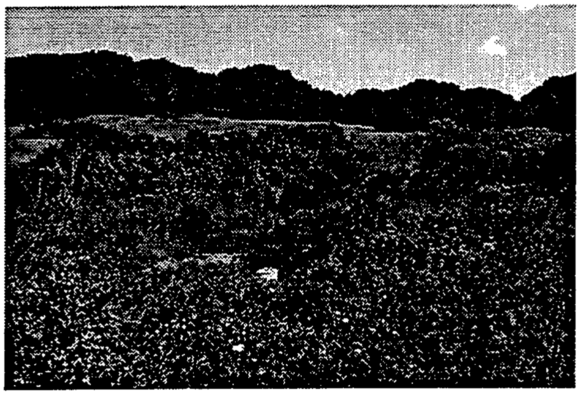
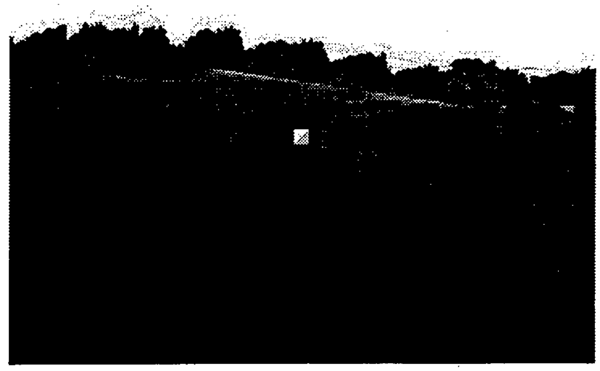
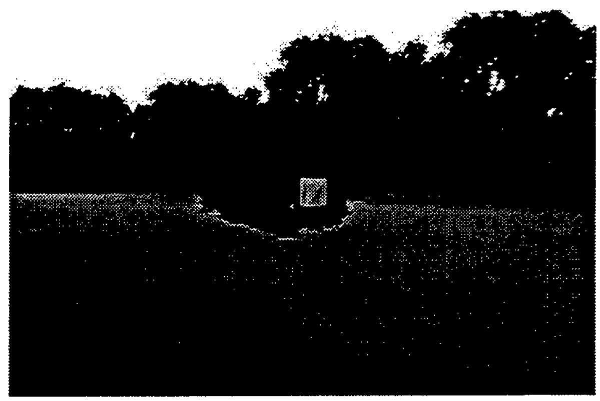
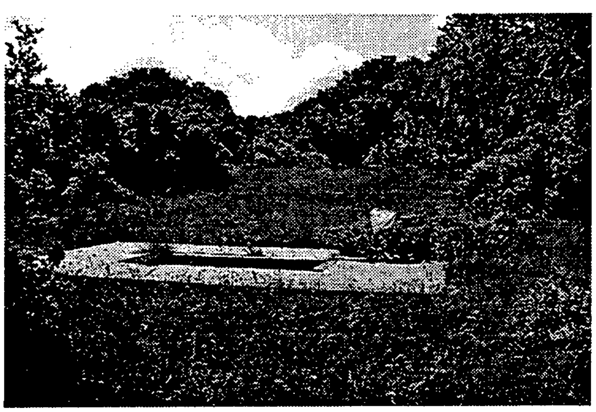
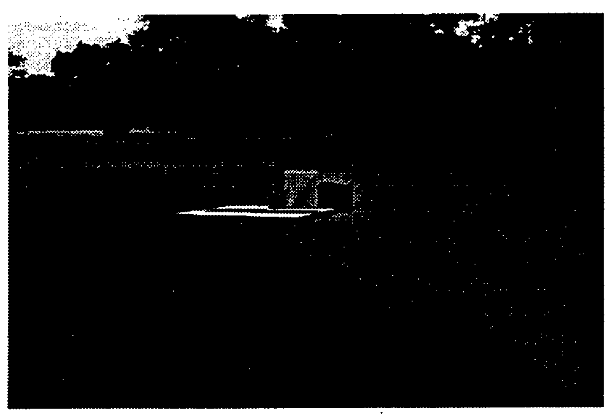
Control Point 2

Control Point 2



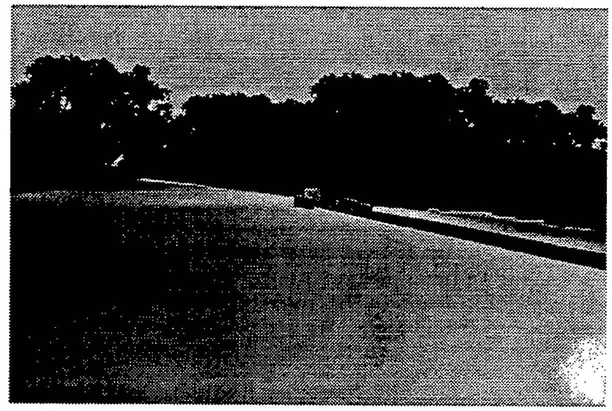
Control Point 3

Control Point 3

Real World	Model
	
Control Point 4	Control Point 4
	
Control Point 5	Control Point 5
	
Control Point 6	Control Point 6

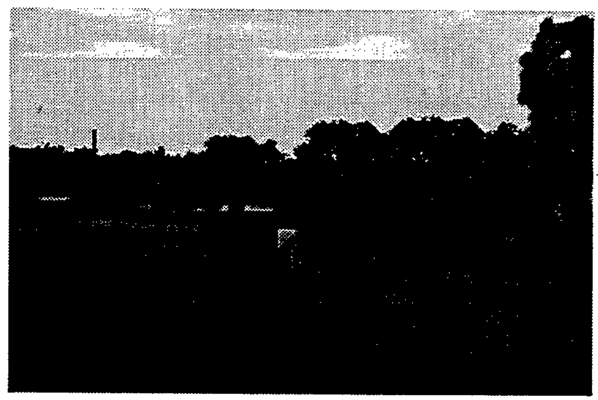
Real World	Model

Control Point 7



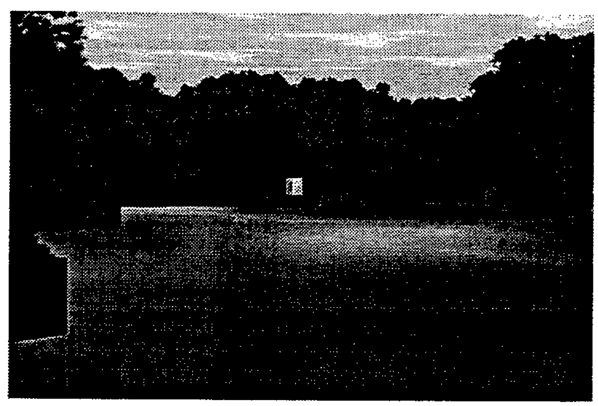
Control Point 7

Control Point 8



Control Point 8

Control Point 9



Control Point 9

APPENDIX J. COURSE EQUIPMENT CHECKLIST

Binder Containing:

_____ Subject's map & designated route

_____ Think Out Loud Instructions

_____ Data Collection Sheet

_____ Researcher's Script

Data Recording:

_____ blue alcohol pen to record route deviations

_____ red pen to record data

_____ digital camera

_____ helmet & 8mm camera

_____ rucksack frame w/GPS system

_____ stop watch/timer

Misc:

_____ extra battery (8mm camera)

_____ extra cassette (8mm camera)

_____ extra Color Wheels for Tasks 3.1. & 5.1

_____ extra arrows (color wheels)

_____ extra clue sheet (incase subject looses his/hers)

_____ blindfold (for movement to course)

_____ cellular phone (*optional*)

_____ compass

_____ first aid kit

_____ Tecnu (for poison oak)

_____ water

Prepositioned:

_____ Color Wheel Platform for Tasks 3.1. & 5.1

_____ Control flags

APPENDIX K. THINK OUT LOUD INSTRUCTIONS[1]

Your thoughts are important to this research. As you navigate the course you should be "thinking out loud".

As you move through the environment and experience it directly express what you are thinking. The mental preconception you had of this environment before you stepped into it will now be evaluated by you as you experience the course directly. As this image is confronted with direct experience your expectations and plan may be confirmed, modified, or refuted. Be sure to talk out loud these thoughts.

The process of talking out loud and paying close attention to your route will slow you down. This is expected and why you are given an hour to finish the course.

PLEASE SPEAK LOUDLY SO THAT YOUR VOICE WILL BE PICKED UP BY THE MICROPHONE

[1] This document is adapted and modified from MAJ Banker's Masters Thesis [BANK 98]

APPENDIX L. ROUTE CLASSIFICATIONS

1. GENERAL

This appendix consists of five items: route analysis, an explanation of route classifications for each leg of the course [BANK 97], route classifications based on a LISP Program, participant route classifications based on MAJ Banker's route classification and on the LISP generated routes, and optimal route plan for movement from Control Point 9 to Control Point 4. The explanation of route classifications for each leg of the course is taken directly from Appendix F of MAJ Banker's 1997 Masters Thesis.

Route classifications were utilized to categorize the difficulty of an individual's planned routes for comparison to their navigational ability. Routes were classified using MAJ Banker's route classification listing (Appendix L.3) and again utilizing the results of a LISP route planning program (Appendix L.4).

2. ROUTE ANALYSIS

Participant routes were analyzed for difficulty level and performance. Participants' Leg Error Scores were correlated with their Leg Difficulty Rating and ability level. A simple analysis of ability level to planned route difficulty shows that participants with higher GZ Scores and a high-perceived level of navigation ability planned simpler routes (Figure L.1).

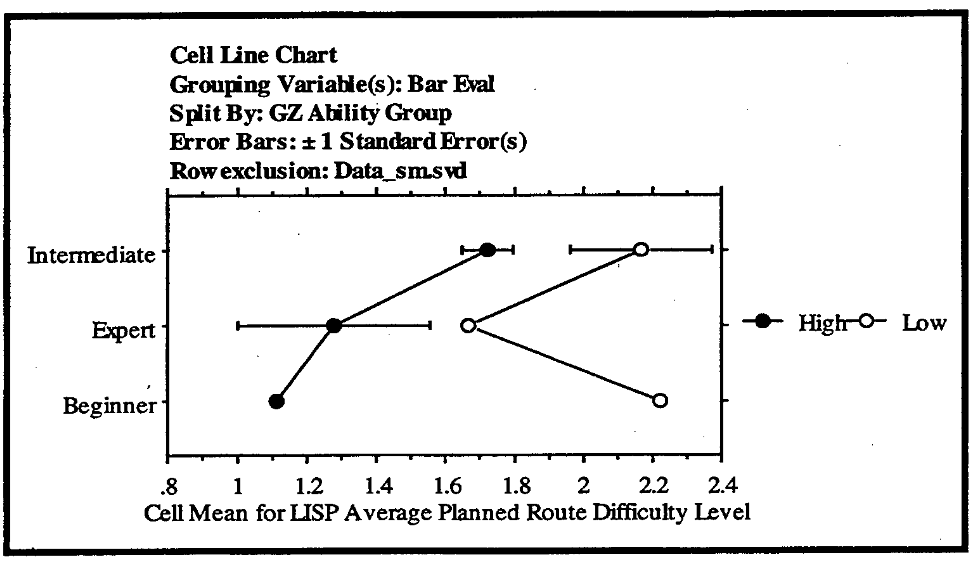


Figure L.1. Group vs LISP Planned Route Difficulty by Guilford-Zimmerman Scores

This suggests that individuals with higher spatial ability have the ability to recognize desirable landmarks on the course and plan more conservative routes to locate those landmarks in route to their objective. Participants who ran short of time during the study phase due to becoming disoriented in the training environment or failed to maximize the tools they were afforded, hastily planned their final legs which usually resulting in an azimuth and distance approach to the problem. A straight distance and azimuth usually forced participants to negotiate thickly vegetated terrain, in which they became entangled and veered off their intended course, resulting in an increased number of errors.

Figure L.1 suggests that routes generated by a LISP program may provide us with the ability to predict routes would be best suited for a group based on the team's spatial abilities and navigational experiance. If participants plan routes, which are more difficult than their ability level (Appendix L, Section 4), the chances they will fail to successfully execute the planned routes increases while intermediate navigators who plan routes closer to the beginner level than the intermediate level also find fewer controls (Figure L.2). Advanced navigators plan routes just below the intermediate level and perform very well as they plan and operate within their abilities.

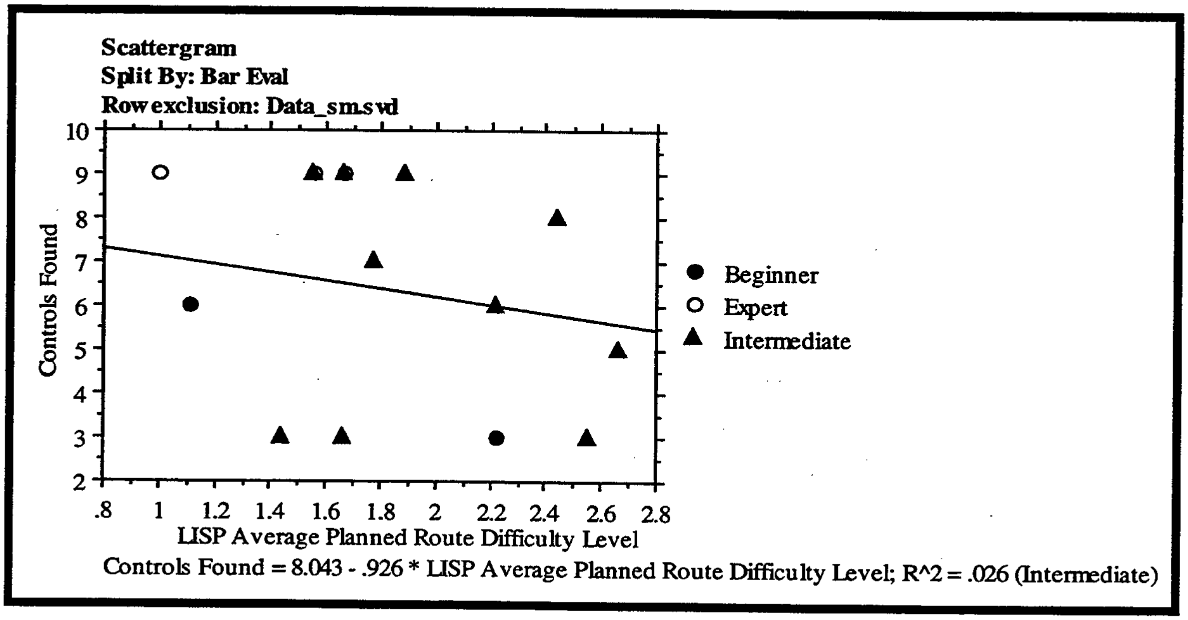


Figure L.2. Performance Based on Ability and LISP Average Route Difficulty

The same results are present when comparing performance based on ability levels and ISOM Average Route Difficulty Levels (Figure L.3).

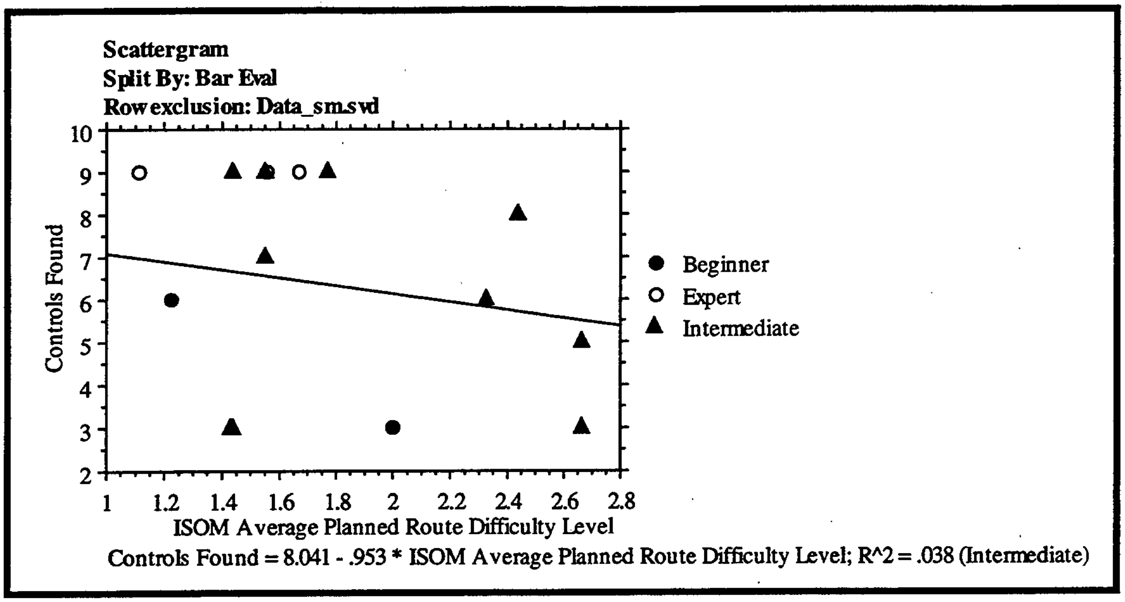


Figure L.3. Performance Based on Ability and ISOM Average Route Difficulty

Conversely, if a program can generate a preplanned route through an environment with respect to mission requirements and individual navigational abilities, we can reduce the mission planning time by military personnel and concentrate on mission rehearsal. Of course, such routes must be reviewed, modified, and verified by the personnel conducting the operation to ensure they understand and feel comfortable with the route.

Further research needs to be conducted to determine if we can accurately predict an individual's navigational performance based on their abilities and the difficulty level of planned routes. This research depends on our ability to evaluate an individual's navigational ability and produce a program that can plan viable routes based on mission requirements and terrain characteristics. The LISP program in Appendix L.4 is a rough draft attempt which takes into account many of the aspects which must be considered if such a route planning tool is to be developed.

3. BANKER'S ROUTE CLASSIFICATIONS

What follows is MAJ Banker's classification of some of the most probable routes to a given control and is based on the International Specification for Orienteering Maps [INTE 90]. They do not represent the only ways of getting to a control but the most likely routes chosen by participants based upon MAJ Banker's orienteering experience

and knowledge of the terrain. The classifications are used as a basis for comparison with the routes selected by the LISP Route Selection Program. All controls possess at least one beginner's route. The proportion of handrails to catching features delineates intermediate and advanced routes. If there are more handrails as compared to catching features then the route is intermediate. The opposite is true if there are more catching features to handrails. Utilizing MAJ Banker's method to classify routes taken by participants, if an exact match for a participant's route could not be found from the below list, the route was examined within the context of its use of handrails (including what type) and catching features and assigned a route designation. This designation correlates with the same level of difficulty for the routes on that control (beginner, intermediate, advanced) [BANK 97].

a. Control 1.

1. Beginner

a) Gigling Road west to jeep trail
b) Jeep Trail south by east by south to building
c) Control on NW corner of building

2. Beginner

a) Watkin's Gate Cutoff to indistinct path.
b) Indistinct path southwest up hill to jeep trail
c) Jeep Trail west to building
d) Control on NW corner of building

3. Intermediate

a) West through plotted individual trees (catching features)
b) Handrail rough open ground south to junction indistinct path and jeep trail
c) Jeep Trail west to building (catching feature)
d) Control on NW corner of building

4. Advanced

a) West through plotted individual trees
b) Follow runnable forest southwest
c) Try to hit small rough open gap by keeping walkable forest to left shoulder

d) Use forest fight to west as catching feature if needed
e) Control on NW corner of building
f) Use jeep trail for catching feature if control is missed

5. Advanced

a) Go straight at control from start

b. Control 2.

1. Beginner

a) Jeep trail northwest to building
b) Follow open ground to west and look for rough open clearing going northwest (handrail)
c) Follow rough open clearing northwest looking for pit
d) Control in pit

2. Intermediate
a) Jeep trail northwest to building
b) Go straight at control (WSW) from building

3. Advanced
a) Set out on straight line directly for control
b) Hit open ground and look for building on the right and rough open break on the left. (Catching feature)
c) Follow rough open clearing northwest looking for pit
d) Control in pit

c. Control 3.

1. Beginner

a) Head northwest and get out onto Gigling Road
b) Take Gigling Road west to jeep trail junction with telephone pole
c) Take jeep trail southeast to convergence of two jeep trails
d) Head southwest into tree grove looking for control

(1) Use building as catching feature
(2) Use open ground to west as backup catching feature

e) Control hanging from tree limb

2. Advanced

a) Head straight at control; use jeep trail prior to control as catching feature
b) Head southwest into tree grove looking for control

    (1) Use building as catching feature
    (2) Use open ground to west as backup catching feature

c) Control hanging from tree limb

d. Control 4.

1. Beginner

    a) Head southwesterly and try to get on jeep trail headed in same direction
    b) Take jeep trail to junction
    c) Take jeep trail southeast to junction
    d) Take southerly fork to next junction
    e) Take fork to northwest
    f) Once beyond patches of fight leave trail and start looking for control
    g) Control is in pit

2. Beginner

    a) Turn around and go back to jeep trail to the east
    b) Take jeep trail southwest to junction
    c) Take fork to the south to another junction
    d) Take fork to the west to next junction
    e) Take southerly fork to next junction
    f) Take fork to northwest
    g) Once beyond patches of fight leave trail and start looking for control
    h) Control is in pit

3. Intermediate

    a) Go south towards road junction
    b) Get on road and take to junction
    c) Take road west to other road junction
    d) Handrail around fight to west coming down through small patch of fight into control

4. Advanced

a) Head straight at control expect to hit jeep trail that runs NW to SE (catching feature)
b) Hit trail and then thread way through scattered fight
c) Emerge into center of depression and rough open ground, (catching feature) look for pit
d) Control is in pit

e. Control 5.

1. Beginner

a) Move back out onto jeep trail
b) Take trail west to trail junction
c) Take trail WNW up to misc object
d) From misc. object go straight at control

2. Intermediate

a) Move directly at control
b) Use Gigling Road as catching feature if miss on control
c) Control is in center of clearing

3. Advanced

a) Move directly at control
b) Use southwesterly linear clearing as catching feature
c) Follow clearing NW right into control
d) Use Runnable forest along Gigling as catching feature in case of miss

f. Control 6.

1. Beginner

a) Move out onto Gigling Road and take it westerly to junction with dirt road
b) Move down dirt road (south) to junction with jeep trail
c) Take jeep trail to east look for concrete rubble
d) Move southeast through runnable forest
e) Look for control on concrete pad

2. Beginner

a) Move straight at control and hit jeep trail
b) Go southwest on Jeep trail to junction with another jeep trail

c) Take jeep trail westerly and look for concrete rubble
d) Move southeast through runnable forest
e) Look for control on concrete pad

3. Intermediate

a) Move south to junction of two jeep trails (catching feature)
b) Handrail jeep trail southeasterly to clearing (catching feature)
c) Handrail clearing to the west
d) Hit fight going west (catching feature) and move south
e) Handrail fight (keeping it on right shoulder) into control
f) Look for control on concrete pad

4. Advanced

a) Move straight at concrete rubble (aiming off technique) use jeep trail as catching feature and handrail
b) Move southeast through runnable forest
c) Look for control on concrete pad

g. Control 7.

1. Beginner

a) Move back out onto east west jeep trail
b) Go west to junction of jeep trail and dirt road
c) Take dirt road south to junction with four jeep trails
d) Take jeep trail east by northeast
e) Look for second linear break in vegetation (indistinct path)
f) Take indistinct path (handrail) to ditch
g) Follow ditch to its end
h) Control at east end of ditch

2. Intermediate

a) Move through rough open ground easterly to jeep trail (catching feature)
b) Follow jeep trail (handrail) to junction with other jeep trail by building
c) Locate telephone poles and follow wire (handrail) south easterly
d) Hit fight and turn west and follow fight boundary into ditch (handrail)
e) Control at east end of ditch

3. Advanced

   a) Move through rough open ground easterly to jeep trail (catching feature)
   b) Take jeep trail to curve where it turns east (hand rail)
   c) Leave jeep trail and head straight for control use east west jeep trail as checkpoint (catching feature)
   d) Aim off to east side of ditch and go southeast (telephone wires to east as catching feature to prevent drifting too far east)
   e) Use fight as catching feature
   f) Hit fight and turn west and follow fight boundary into ditch
   g) Control at east end of ditch

4. Advanced

   a) Move straight at control
   b) Use jeep trail junction as attack point
   c) From attack point take offset route to west part of ditch
   d) Follow ditch to east and find control at end of ditch

h. Control 8.

1. Beginner

   a) Handrail fight to the east till hitting the jeep trail
   b) Follow jeep trail northerly through intersection to sharp curve to the east
   c) Once at sharp curve to east turn off trail to west and look for control in clearing
   d) Control located in clearing

2. Intermediate

   a) Handrail fight to telephone poles
   b) Take telephone poles NW back to jeep trail junction
   c) Follow jeep trails east to next junction
   d) Take jeep trail north
   e) Leave jeep trail and move directly at control

3. Advanced

   a) Move directly at control (avoiding forest walk) use jeep trail junction as catching feature

b) From jeep trail junction aim off to east of control at sharp curve to east of jeep trail keeping eyes open for control in clearings

c) Use same trail as Beginner route as catching feature (for drift)

i. Control 9 (Finish)

1. Beginner

a) Move back out to jeep trail just to east of control 8
b) Take trail south to four way junction with other trails (handrail)
c) Take southeasterly running trail to trail fork
d) Take northeasterly running fork to five way junction (handrail)
e) Take northwesterly running trail keeping eyes open for small break in fight to the east (catching feature)
f) Take indistinct path into clearing and hook to north
g) Control on east edge of clearing

2. Intermediate

a) Move back out to jeep trail just to east of control 8
b) Move off trail using rough open to move closer to control
c) Take rough open out onto jeep trail which runs NE to SW
d) Take trail to junction with North South jeep trail
e) follow jeep trail looking for indistinct path
f) Take indistinct path into clearing and hook to north
g) Control on east edge of clearing

3. Advanced

a) Move straight at control on east by northeast azimuth
b) Use trail as catching feature
c) Fight to north and south of route used as catching features
d) Locate opening in fight
e) Take indistinct path into clearing and hook to north
f) Control on east edge of clearing

4. LISP PROGRAM ROUTE CLASSIFICATION

This program plans a route through a specified piece of terrain based on identifiable decision points and terrain characteristics. The information is manipulated by a branch and bound search, pruning heuristics, and terrain classification. The algorithms are coded in ANSI LISP. Because of the memory requirements of the search's stacks and

the speed of the processors running the program, each leg was limited to passing through a maximum of eight decision points. This limitation forced the rejection of possible routes.

Decision points are identified as any piece of terrain that would logically require an individual to make a decision on which direction to move. Although in a natural environment, a person on foot can move in almost any direction at any time, it was assumed that individuals would not intentionally change direction of movement unless they knew where they were and where they wanted to go. For this course, 99 decision points were identified. Decision points were associated with neighboring decision points based on proximity (Figure L.4). This meant that to traverse the course, the program had to link together neighboring decision points into a chain of successive segments to complete each leg of the course.

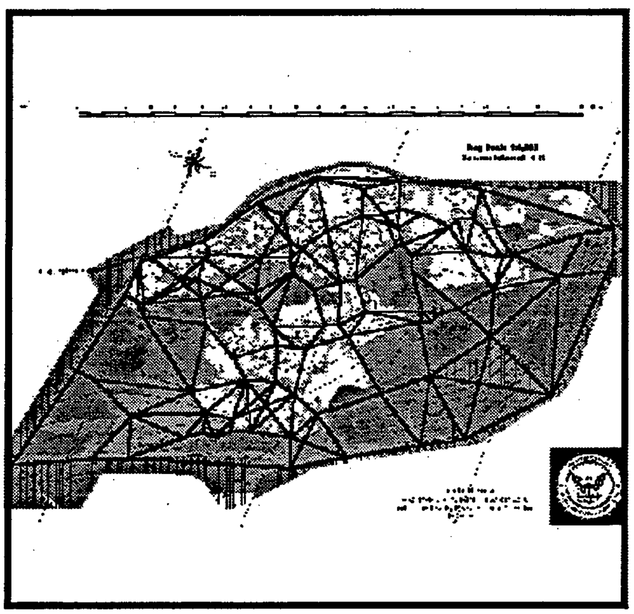


Figure L.4. Decision Points and Neighbors

The terrain between neighboring decision points is known as a segment. Each segment has a different point value based on a list of characteristics. This program utilized four factors (distance, mobility, observation, and difficulty of locating the next decision point) to determine segment values. Two additional factors which were not incorporated but which would have made the program more accurate are change in elevation and terrain revisited.

Distance between points is not assigned any additional weight in the program's algorithm. Mobility is based on the difficulty of traversing the terrain. Mobility factors came directly from the terrain classification used on the orienteering map. Observation is also evaluated based of the orienteering map's terrain classifications. Observation deals with the ability to see through or over the terrain's vegetation. The final factor addressed is the issue of identifying when an individual has reached the decision point. Some decision points are easier to locate than others are. For example, it is more difficult to locate a control point placed in a pit as compared to a black shed in the middle of a clearing. The weights assigned for each of these factors was dependent on the ability level of the navigator (Tables L.1, L.2, and L.3).

Ability Group	*Fight*	*Walk*	*Sand*	*Run*	*Open*	*Road*
Beginner	4.0	2.5	1.75	1.5	1.25	1.0
Intermediate	3.0	2.5	2.0	1.5	1.25	1.0
Advanced	2.0	1.1	1.075	1.05	1.0	1.0

Table L.1. LISP Program Mobility Weights

Ability Group	*Forest*	*Undergrowth*	*Open*
Beginner	4.0	2.75	1.0
Intermediate	3.0	2.0	1.0
Advanced	1.2	1.1	1.0

Table L.2. LISP Program Observation Weights

Ability Group	*Hard*	*Moderate*	*Easy*
Beginner	5.0	2.0	1.0
Intermediate	3.0	1.5	1.0
Advanced	1.5	1.2	1.0

Table L.3. LISP Program Identification Weights

Weights were based on the impact of each element to the successful completion of a segment for each type of individual. The most difficult condition receives the highest weight. The lowest weight, easiest aspect, which could be assigned for any element is 1.0. For all individuals traversing the terrain on a road with open visibility to an easily identifiable decision point was weighted the same, 1.0. Conditions are rank

ordered from hardest to easiest and then assigned weights based on their position in the table.

Mobility through the terrain was closely coupled for each group. This is based on observations that indicated little difference between ability groups in the level of apprehensiveness of individuals who were faced with conducting cross-country movement. The most difficult terrain to cross, Fight, was weighted as a 4.0 for a beginner, 2.0 for an intermediate and 1.0 for and advanced navigator. These weights were based on the difficulty for beginners to maintain their course while traveling through fight, since they need constant verification that they are going in the correct direction. Intermediate navigators have fewer problems maintaining their course through difficult terrain but still require some assurance they are on the right course. Advanced navigators are more confident in their abilities, need less reassurance they are on the correct course and often plan their route to use catching features to confine their movement and halt their forward progress in the proximity of the next identifiable decision point.

Visibility plays much less of a factor for advanced navigators than for intermediates or beginners. Intermediate and beginning navigators needs reassurance that they are on the right course. This is gained through many cues in the environment most of which are visual. Advanced navigators can gain reassurance through many senses such as the sound of a creek to the north or the warmth of the sun on the left side of their face. Because of this, navigators pay less attention to visual cues enroute to their objective as they confirm their position through the use of many input factors. This results in reducing the weight of the most cluttered environments to 1.2 for advanced navigators while intermediate navigators remain at 3.0 and beginners remain at 4.0.

Identification of the decision point plays the most crucial part of the segment's value for beginners. If beginning navigators cannot identify when they have reached the correct decision point, they often become confused or disoriented. This results in their becoming lost and losing confidence in their abilities to determine their location and continue their movement in a positive direction. Beginners also have greater difficulty choosing and identifying appropriate decision points since they continuously question their ability. This results in a greater chance of them misidentifying the correct decision

point if it is not an obvious one. For these reasons, the weight for hard to identify decision points for beginners is set at 5.0. Intermediate navigators have fewer problems choosing and identifying appropriate decision points. Since they do not question themselves as often as beginning navigators, they are less likely to incorrectly identify a decision point. The weight of hard to identify decision points for intermediate navigators is set at 3.0. Advanced navigators filter out much of the "noise" of an environment and often choose decision points they can readily identify, ignoring intermediate decision point enroute. For this reason they have less difficulty identifying the correct decision point. The weight for hard to identify decision points for advanced navigators is set at 1.5.

The weights for mobility, visibility, and identification are multiplied with the segment's length. Each segment's value is based on the resulting product. The route with the lowest value for its summed segments is chosen as the best route for that ability group.

The program is designed to locate three optimal paths through the course. One Beginner (Figure L.5), one Intermediate (Figure L.6), and one Advanced Course (Figure L.7) are calculated and displayed on maps for comparison with participant maps. The program also produces a sequential list of decision points or waypoints to traverse in order to complete the course. Each leg of a participant's route is compared to the LISP program route legs. If two LISP routes have legs that are the same, the leg is classified as the easier of the two routes. If a participant's planned route between control points is not the same as any of the computer program's planned routes, the participant's route is assigned a classification which is most closely associated with the participant's route with respect to the program algorithm's defining characteristics.

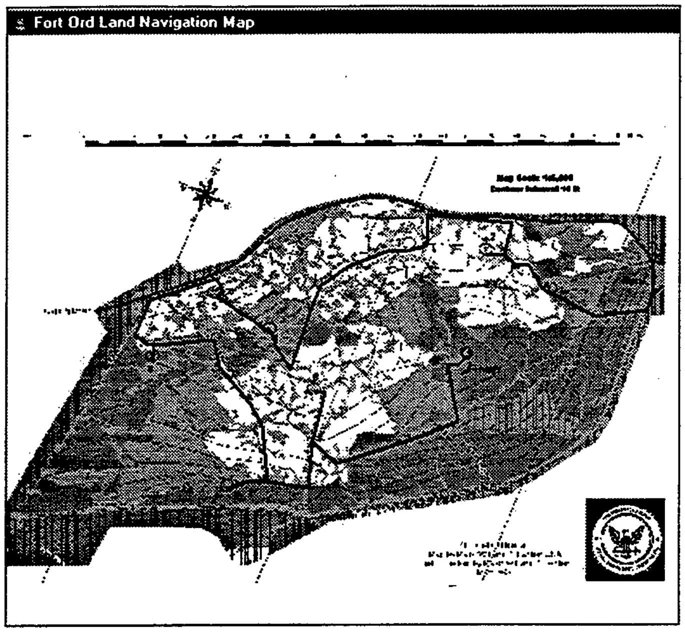


Figure L.5. LISP Beginner Route

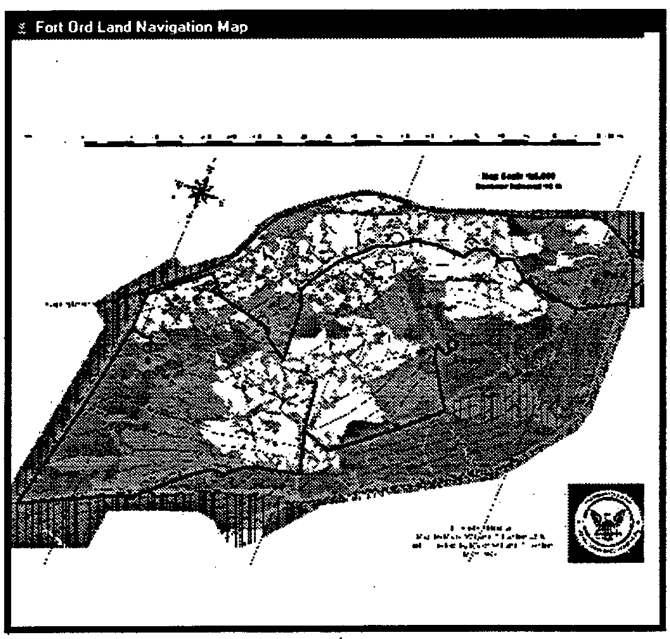


Figure L.6. LISP Intermediate Route

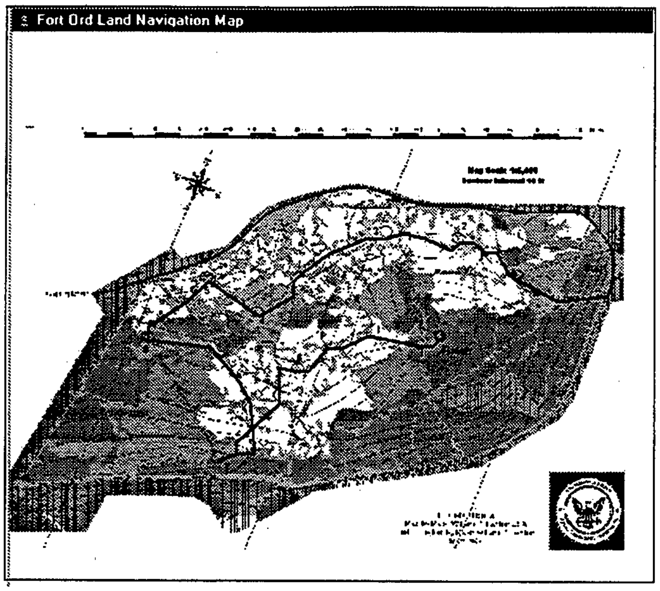


Figure L.7. LISP Advanced Route

5. PARTICIPANT ROUTE CLASSIFICATION

The following are the results of the route classifications (Tables L.4, L.5, and L.6) of each leg of each participant's planned route and the overall route rating for each participant is based on MAJ Banker's route classifications (Appendix L.2) and the LISP Program's route classifications (Appendix L.3). Each leg was evaluated as Beginner (B), Intermediate (I) or Advanced (A). The summation of the routes were assessed by equating each leg classification with a numerical value (Beginner = 1, Intermediate = 2, and Advanced = 3) and summing the value of each leg. The number of legs on the course then divided this value. The resulting aggregate was then used to determine the difficulty level of the entire route. An "X" in the position of errors committed indicates that a participant did not attempt this leg of the route.

		SP-1			*1-2*			*2-3*			*3-4*	
ID	*Banker*	*LISP*	*Errors*	*Banker*	*LISP*	*Errors*	*Banker*	*LISP*	*Errors*	*Banker*	*LISP*	*Errors*
M1	B	B	0	I	B	0	I	I	1	I	I	3
M2	B	B	0	I	B	0	I	I	1	I	I	1
M3	I	I	1	I	B	1	I	I	0	I	I	1
M4	I	I	0	I	B	1	I	I	1	A	A	2
M5	B	B	1	I	B	1	I	I	1	B	B	1
RW1	I	I	0	A	A	1	I	I	0	A	A	2
RW2	I	I	0	B	B	0	I	I	0	A	A	2
RW3	B	B	0	I	B	1	I	I	0	B	B	2
RW4	A	A	1	I	B	3	I	I	1	A	A	2
RW5	B	B	0	B	B	1	I	B	1	B	B	0

		SP-1			1-2			2-3			3-4	
ID	Banker	LISP	Errors	Banker	LISP	Errors	Banker	LISP	Errors	Banker	LISP	Errors
VE1	B	B	1	B	B	0	I	I	1	B	B	1
VE2	B	B	2	I	B	0	I	I	1	B	B	2
VE3	B	B	1	B	I	0	I	I	1	B	B	4
VE4	B	B	0	I	B	0	B	B	1	B	B	2
VE5	A	A	1	A	A	1	B	B	1	I	I	3

Table L.4. Participant Route Classifications

		4-5			5-6			6-7			7-8	
ID	Banker	LISP	Errors	Banker	LISP	Errors	Banker	LISP	Errors	Banker	LISP	Errors
M1	I	I	0	B	I	0	I	I	0	B	I	1
M2	B	B	1	B	I	0	I	I	0	I	I	0
M3	I	I	0	B	I	1	I	I	1	B	I	0
M4	I	I	0	B	B	0	A	A	1	A	A	X
M5	I	I	X	B	B	X	I	I	X	B	I	X
RW1	I	I	0	A	A	1	A	A	X	A	A	X
RW2	I	I	1	A	A	1	A	A	0	A	A	1
RW3	I	I	0	B	I	0	I	I	0	B	I	0
RW4	I	I	X	A	A	X	A	A	X	A	A	X
RW5	B	B	0	B	B	0	B	B	1	B	B	1
VE1	B	B	0	B	I	0	A	I	0	A	A	0
VE2	B	B	X	B	I	X	B	B	X	B	B	X
VE3	B	B	1	A	A	0	B	B	0	B	I	X
VE4	B	B	1	B	I	1	I	B	1	B	B	X
VE5	B	B	X	B	I	X	A	A	X	I	I	X

Table L.5. Participant Route Classifications

		8-9			Totals		
ID	Banker	LISP	Errors	Banker (Tot)	Banker (Ave)	LISP (Total)	LISP (Ave)
M1	B	B	0	14	1.56	15	1.67
M2	B	B	2	14	1.56	14	1.56
M3	I	I	0	16	1.78	17	1.89
M4	A	A	X	21	2.33	20	2.22
M5	B	B	X	13	1.44	15	1.67
RW1	A	A	X	24	2.67	24	2.67
RW2	A	A	X	22	2.44	22	2.44
RW3	B	B	0	13	1.44	14	1.56
RW4	A	A	X	24	2.67	23	2.56
RW5	B	B	1	10	1.11	9	1.00
VE1	I	I	2	15	1.67	15	1.67
VE2	A	A	X	13	1.44	13	1.44
VE3	A	A	X	14	1.56	16	1.78
VE4	B	B	X	11	1.22	10	1.11
VE5	A	A	X	18	2.00	20	2.22

Table L.6. Participant Route Classifications

6. ROUTE FROM CONTROL POINT 9 TO CONTROL POINT 4

During the execution of the course, participants who made it to the end of the course, Control Point 9, were required to describe and execute a route from control Point 9 to Control Point 4. Figure L.8 shows an example of the most efficient route from Control Point 9 to Control Point 4 for a beginning navigator. The program limitations allowed the route to run through a maximum of 10 decision points.

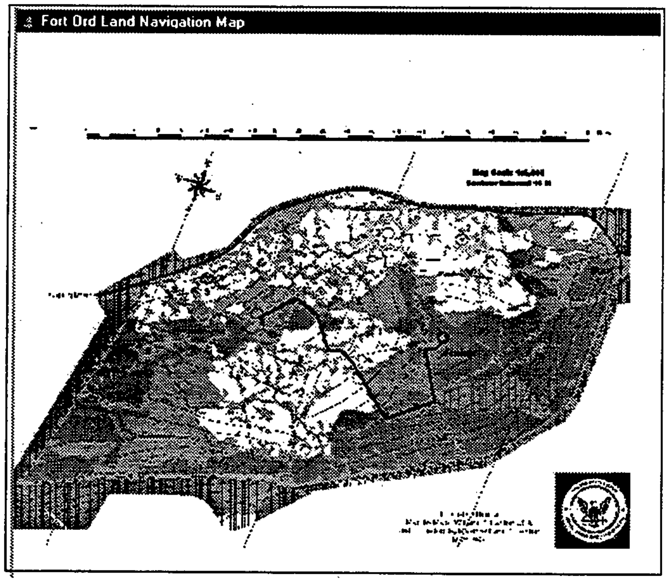


Figure L.8. LISP Beginner Route from CP 9 to CP 4

Because of the limitations of the program, the route depicted is more difficult than the route chosen by any of the participants who performed this task. The LISP route does display characteristics of the routes chosen by the participants. The route travels major trails which have been traversed by the participant in the past. For example the route departs from Control Point Number 9 and heads south down the trail towards the five star intersection. The route then turns to the west and heads down the ridge towards the intersection south of Control Point 9. Compared to the route from Control Point 8 to Control Point 9, this is the same terrain covered by the Beginning and Intermediate navigators.

APPENDIX M. DATA COLLECTION WORKSHEETS

1. TRAINING PHASE DATA COLLECTION SHEET

PARTICIPANT ID:	**Session Date:**		
	Session Start Time:		
RECORDER:	**Session End Time:**		
Initial Subject Study Method:	**a) Study Map**	**b) Read Map and Start Mvt**	**c) Explore Terrain**
Number Compass Checks:			**NA**
Number Map Checks:			**NA**
Number of times subject became "lost":			**NA**
Number of times subject went out of bounds or fell off the edge of the model:			**NA**
Did the subject have difficulty reading the compass?	**Yes**	**No**	**NA**
Did the subject have difficulty reading the map?	**Yes**	**No**	**NA**
Did the subject have difficulty with the model interface?	**Yes**	**No**	**NA**
Comments/Observations:			

2. EVALUATION PHASE DATA COLLECTION SHEET

PARTICIPANT ID:	**Session Date:**
	Session Start Time:
RECORDER:	**Session End Time:**

Task #	Task Description	Tape Counter	Elapsed Time	Num of Errors	New Route	Participant's Actions And Comments	Evaluator's Observations
1	Move to CP #1						
2	Move to CP #2						
3.1.a	Indicate Location SP	N/A	Direction:	Color:	Bearing:		Time:
3.1.b	Indicate Location CP #5	N/A	Direction:	Color:	Bearing:		Orientation:
3.1.c	Indicate Location CP #9	N/A	Direction:	Color:	Bearing:		
3.2	Move to CP #3						
4	Move to CP #4						
5.1.a	Indicate Location CP #1	N/A	Direction:	Color:	Bearing:		Time:
5.1.b	Indicate Location CP #6	N/A	Direction:	Color:	Bearing:		Orientation:
5.1.c	Indicate Location CP #8	N/A	Direction:	Color:	Bearing:		
5.2	Move to CP #5						
6	Move to CP #6						
7	Move to CP #7						
8	Move to CP #8						
9	Move to CP #9						
10.1	Direction and Distance to CP#4 from CP#9	N/A	N/A	N/A	N/A	GO / NGO	
10.2	Directions from CP#9 to CP#4 (Verbal)	N/A	N/A	N/A	N/A	GO / NGO	
10.3	Move to CP#4						
11	White Board Test	N/A		N/A			Order:

Remarks:

APPENDIX N. PARTICIPANT DATA

1. GENERAL

Subject data consists of five items: Map with planned route, map with executed route, of Wheel Test at Control Point #2, of Wheel Test at Control Point #4, and of White Board Test. The errors for deviation from the planned route are located in Appendix O. The angle and distance measurements for the Wheel and White Board Tests can be found in Appendix O.2 and O.3 respectively.

The correct representations for the Wheel and White Board Tests are shown in Figures N.1, N.2, and N.5 respectively. Examples of digital photos of actual subject results for the three tests can be seen in Figures N.3, N.4, and N.6. Subject results for these tests will be displayed with the subject's answers in solid lines or numbers superimposed over the actual answers which are displayed in dashed lines or shaded numbers.

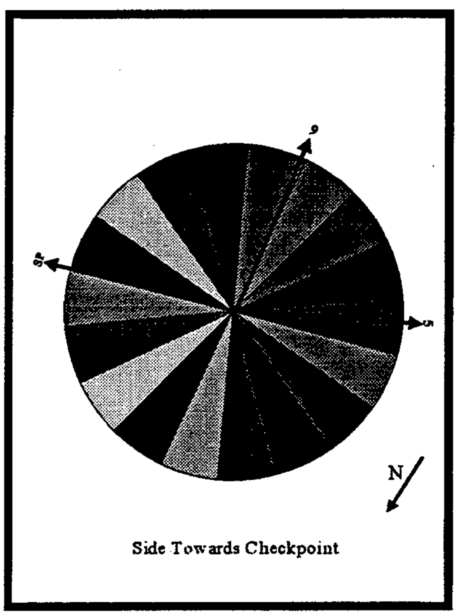


Figure N.1. Correct Wheel Test CP # 2

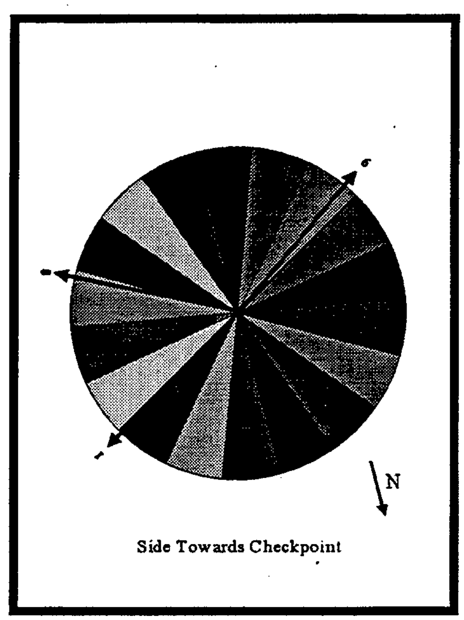


Figure N.2. Correct Wheel Test CP # 4

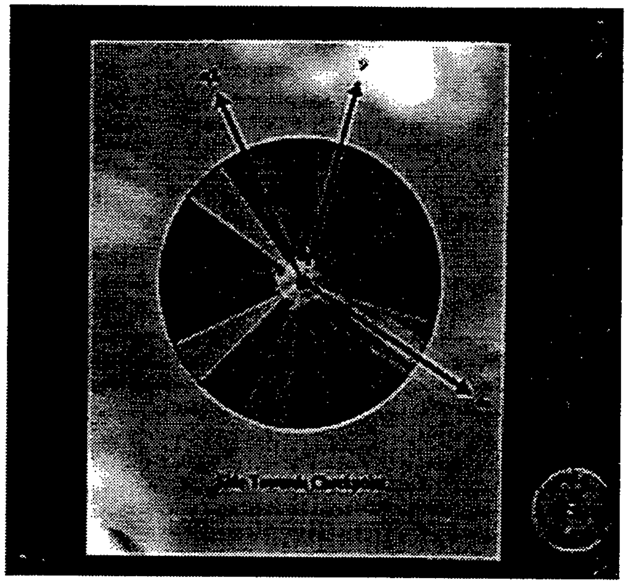


Figure N.3. Example Subject Wheel Test CP # 2

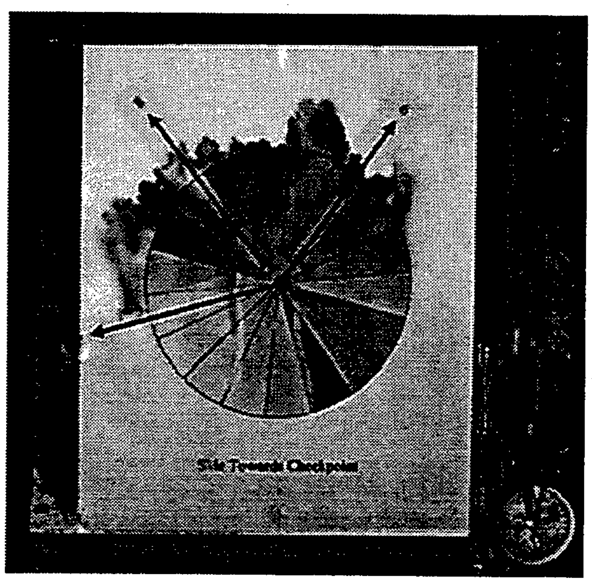


Figure N.4. Example Subject Wheel Test CP # 4

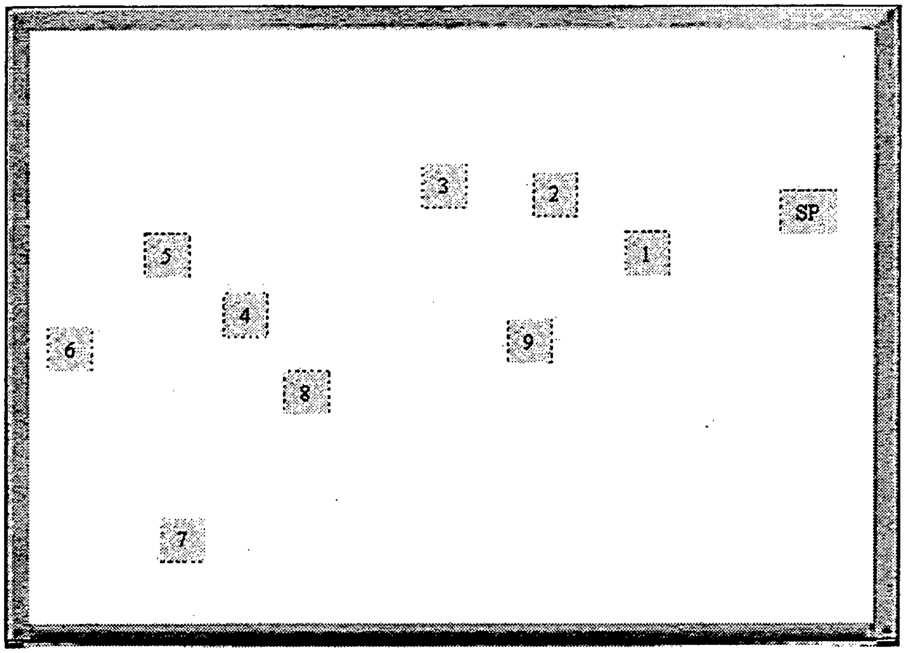


Figure N.5. Correct White Board Test

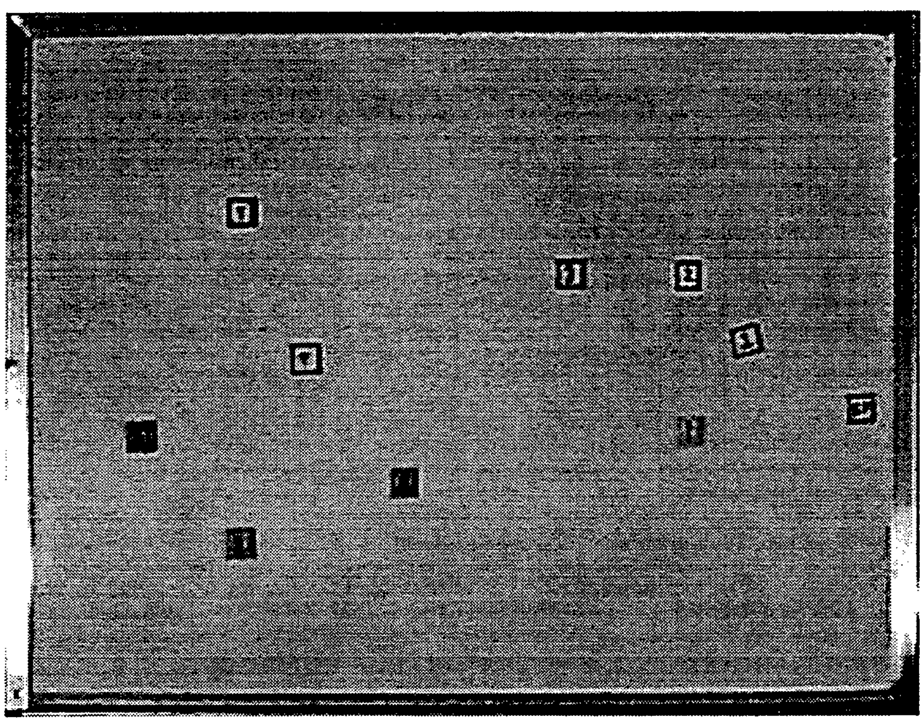


Figure N.6. Example Subject White Board Test

2. MAP PARTICIPANT NUMBER 1

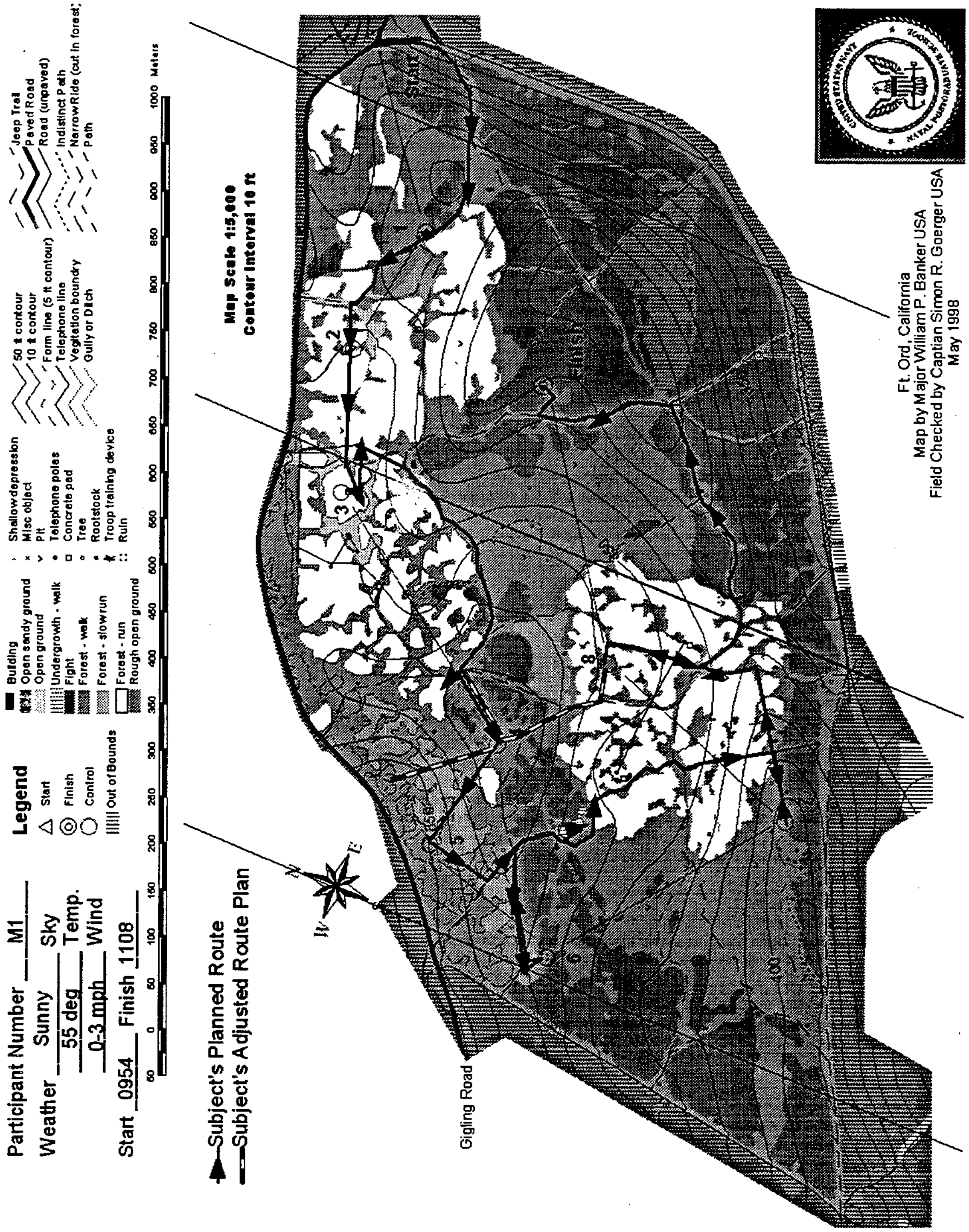


Figure N.7. M1 Planned Route

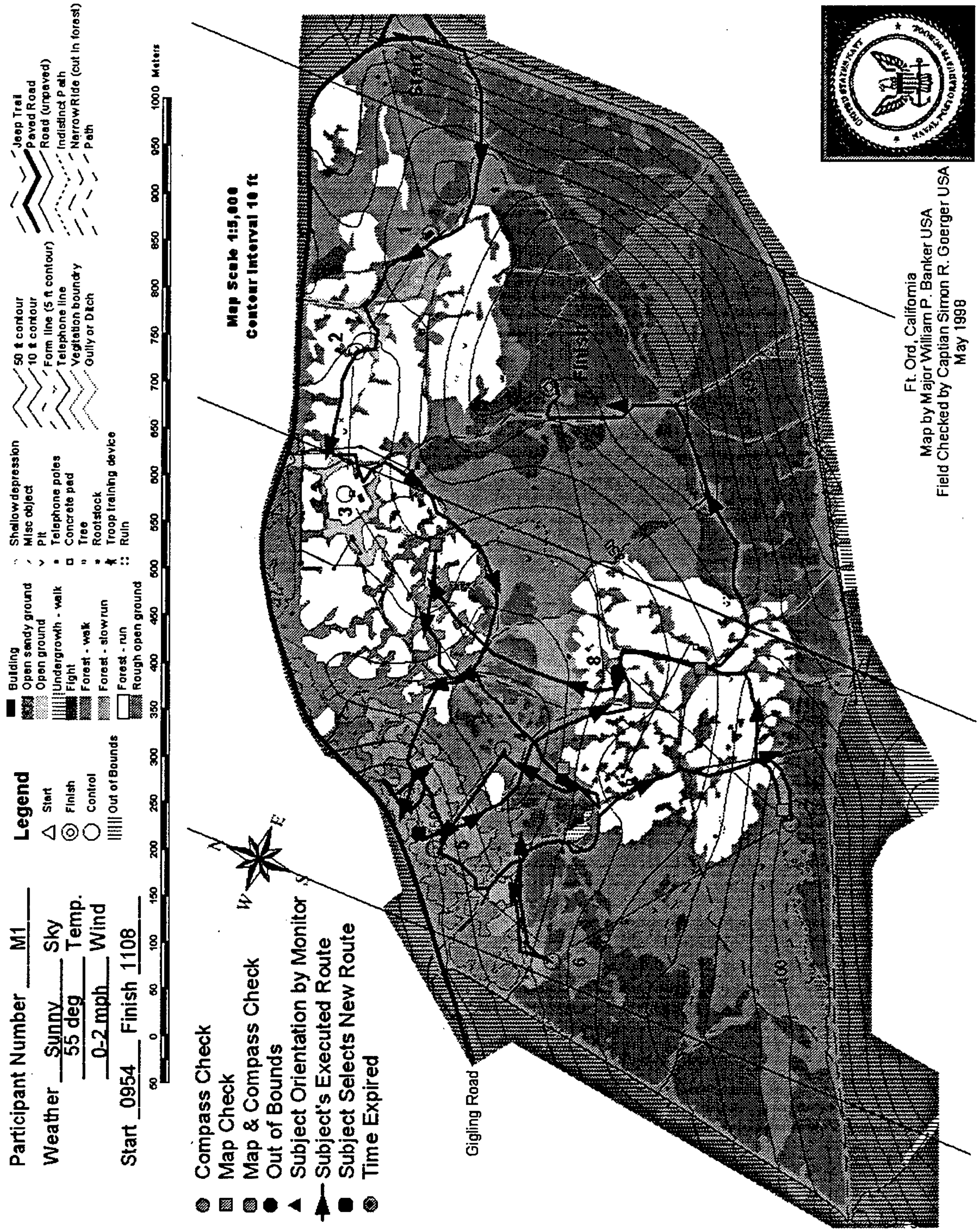


Figure N.8. M1 Executed Route

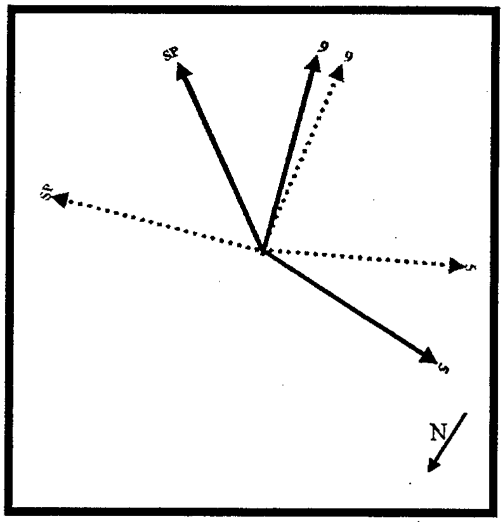


Figure N.9. M1 Wheel Test CP # 2

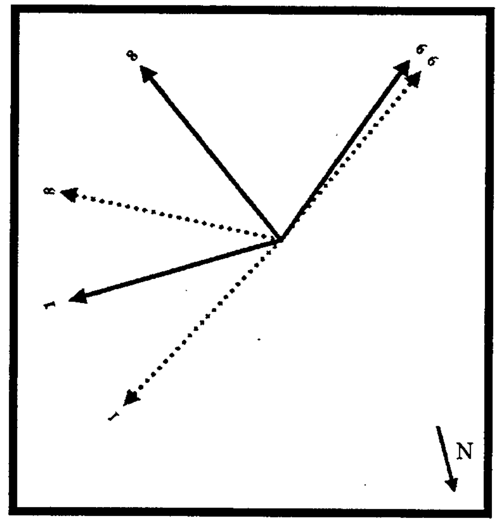


Figure N.10. M1 Wheel Test CP # 4

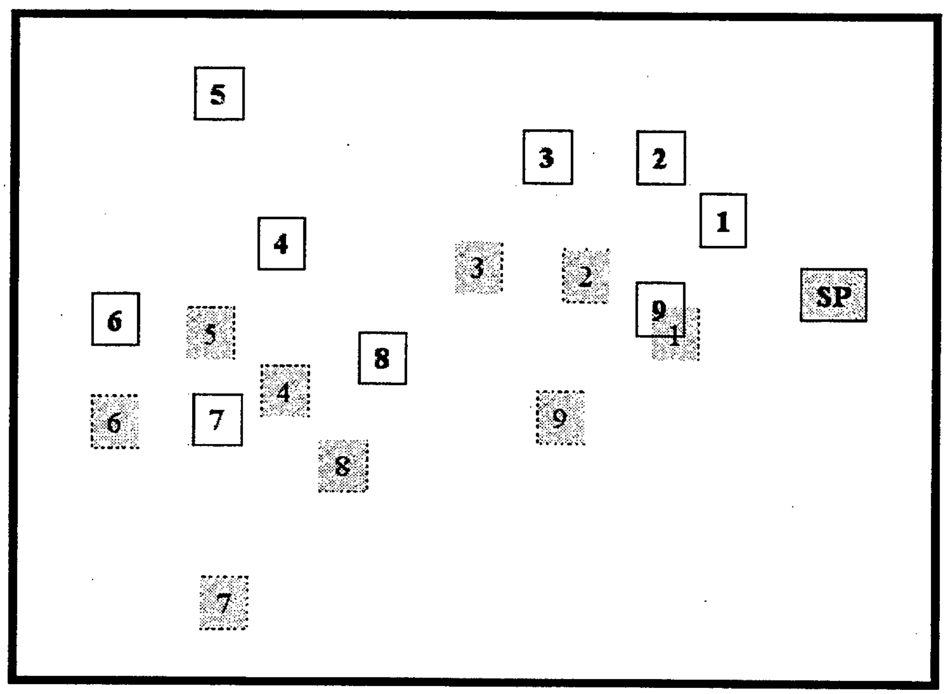


Figure N.11. M1 White Board Test

3. MAP PARTICIPANT NUMBER 2

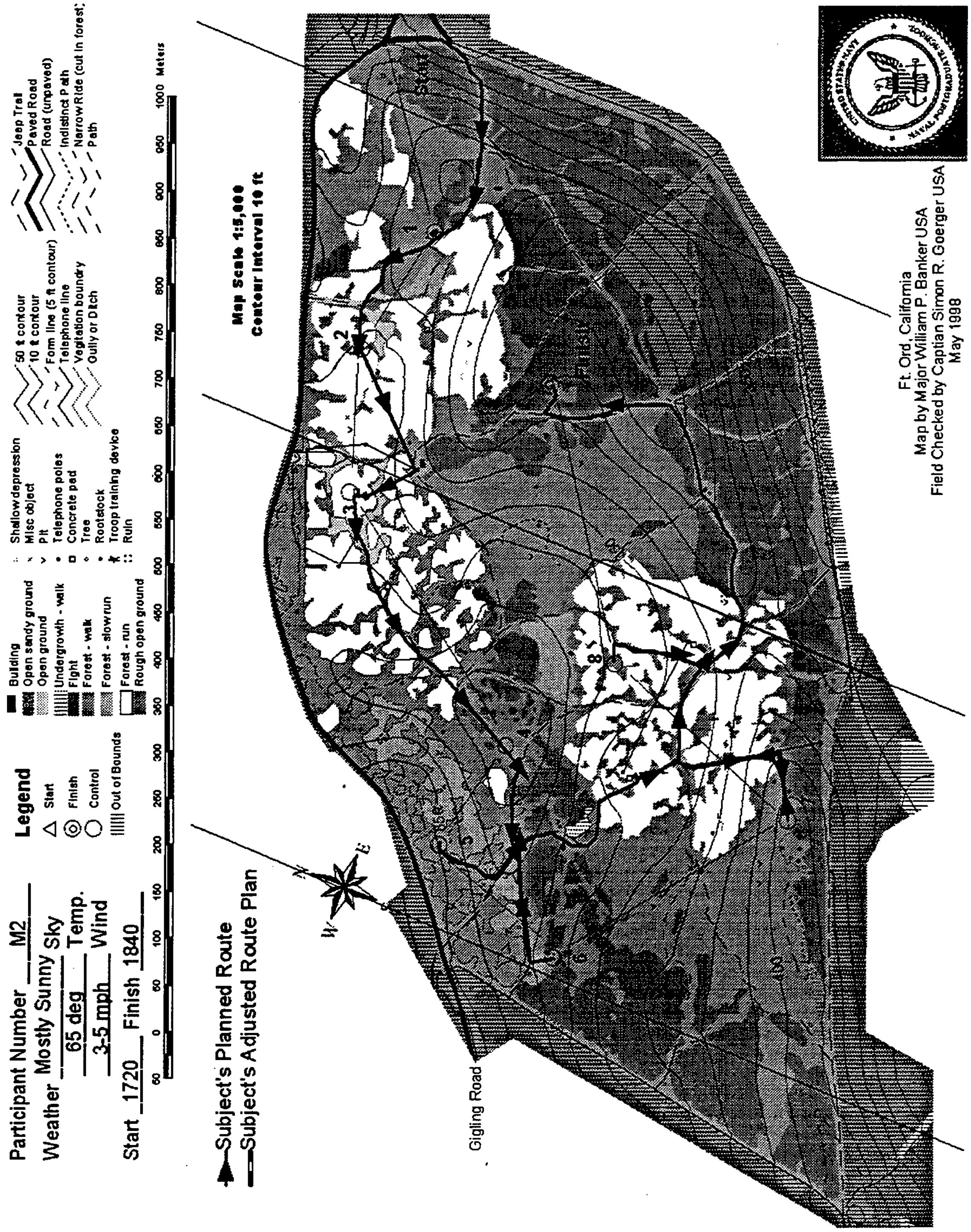


Figure N.12. M2 Planned Route

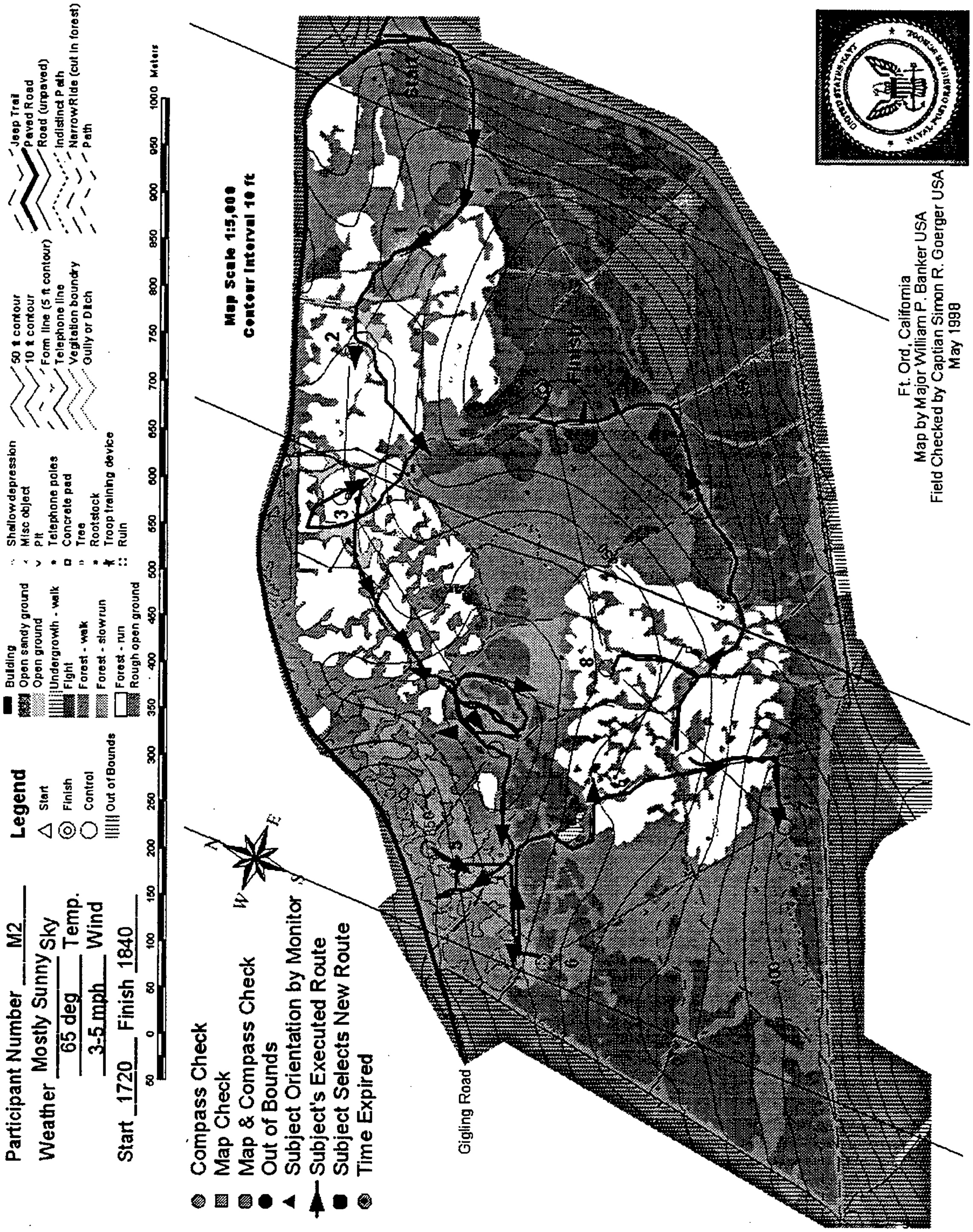


Figure N.13. M2 Executed Route

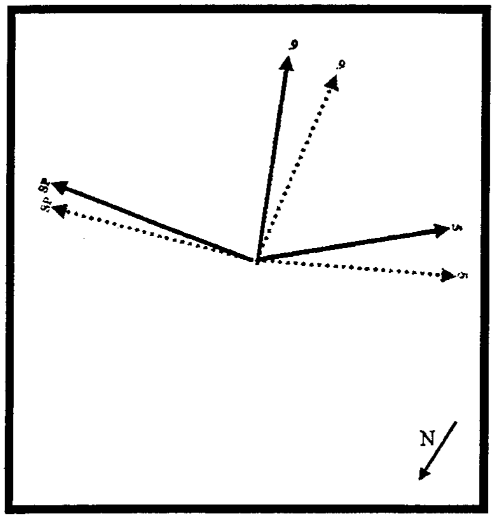


Figure N.14. M2 Wheel Test CP # 2

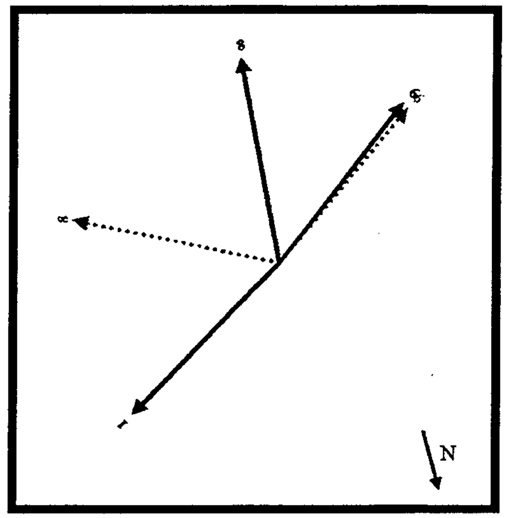


Figure N.15. M2 Wheel Test CP # 4

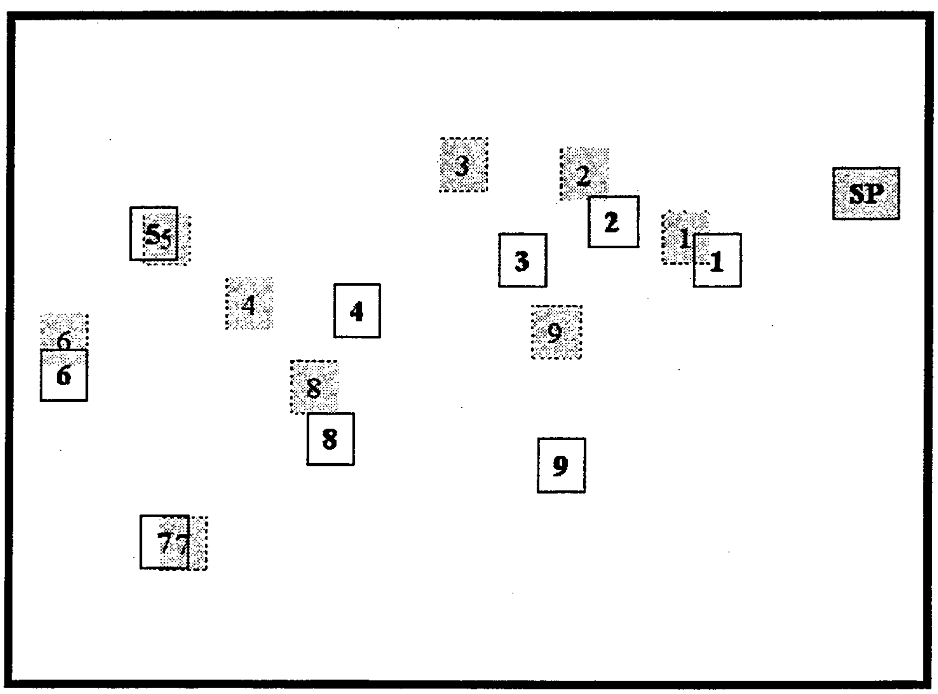


Figure N.16. M2 White Board Test

4. MAP PARTICIPANT NUMBER 3

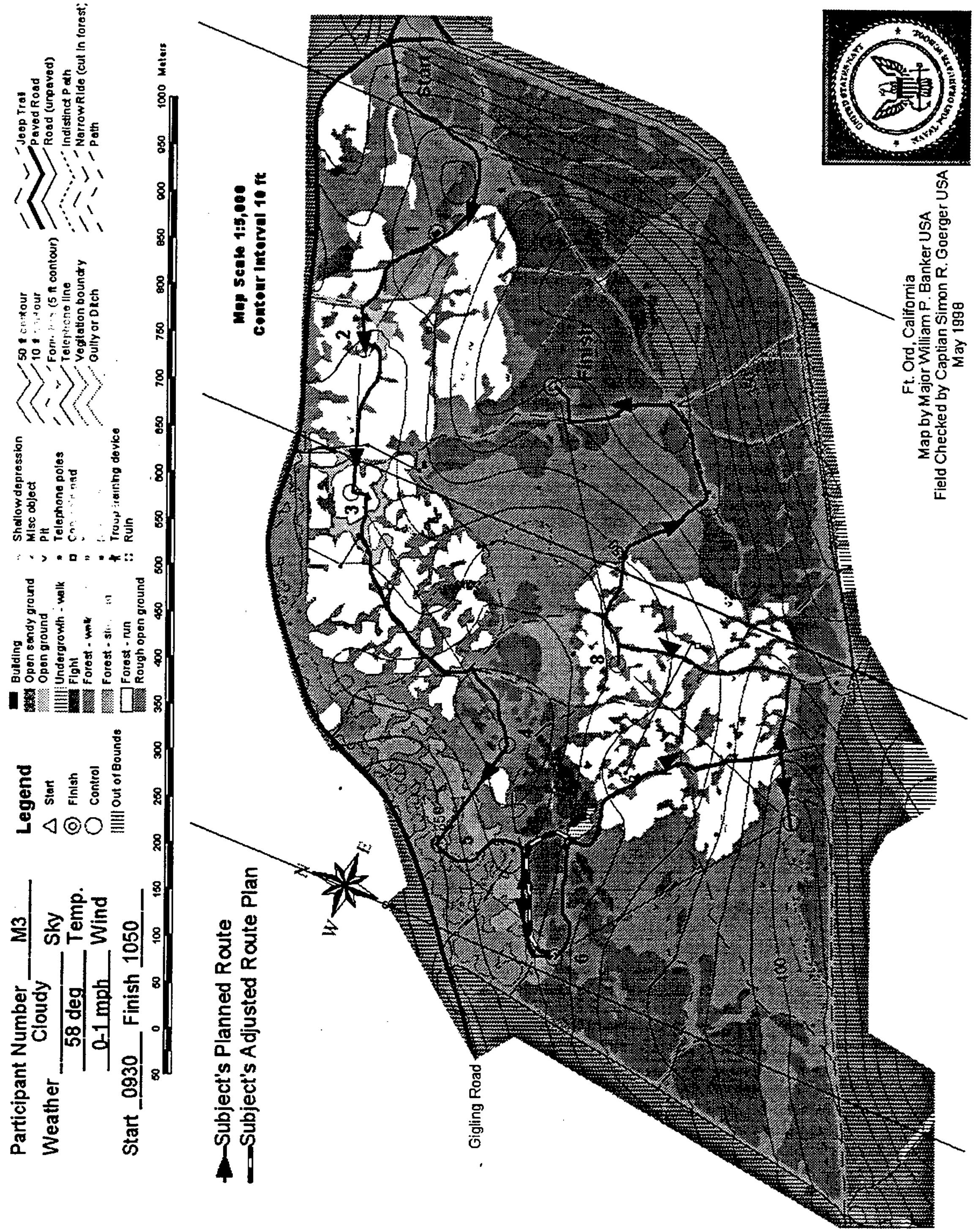


Figure N.17. M3 Planned Route

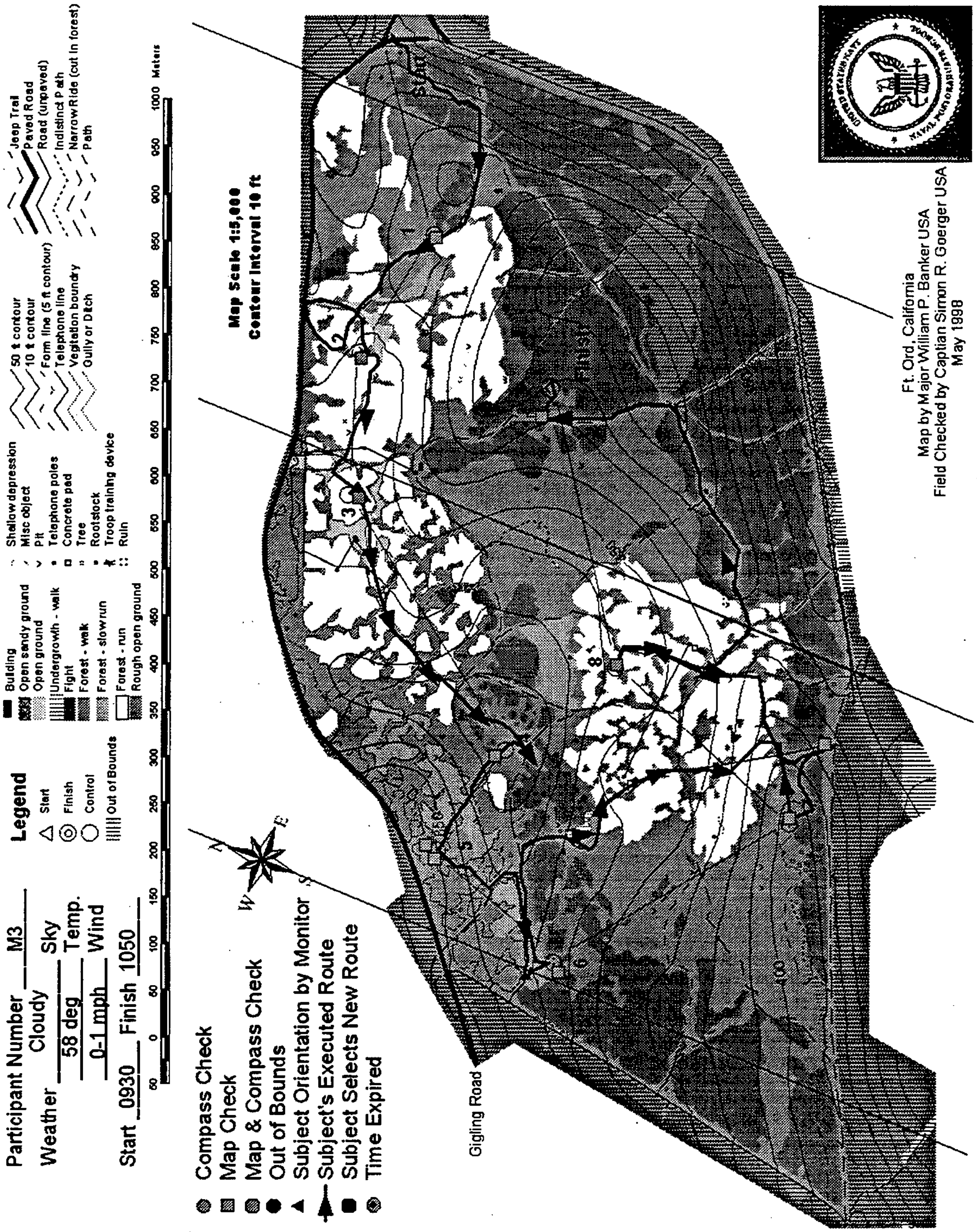


Figure N.18. M3 Executed Route

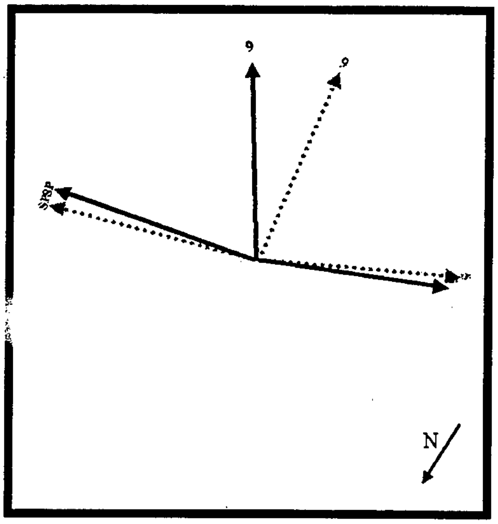


Figure N.19. M3 Wheel Test CP # 2

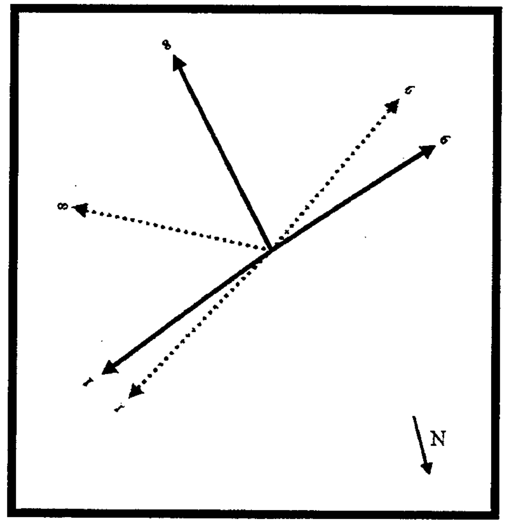


Figure N.20. M3 Wheel Test CP # 4

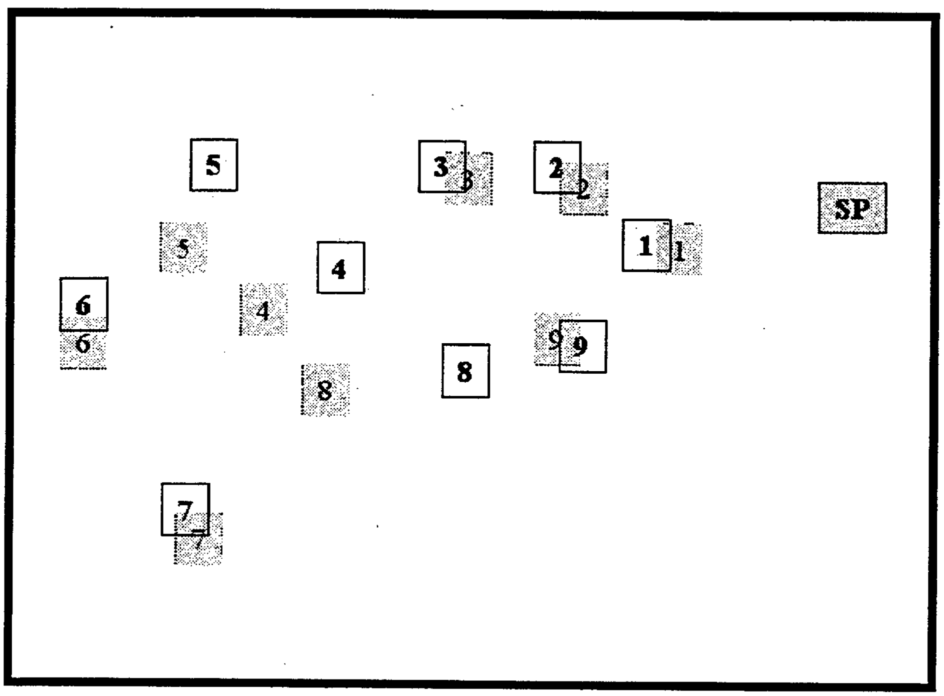


Figure N.21. M3 White Board Test

5. MAP PARTICIPANT NUMBER 4

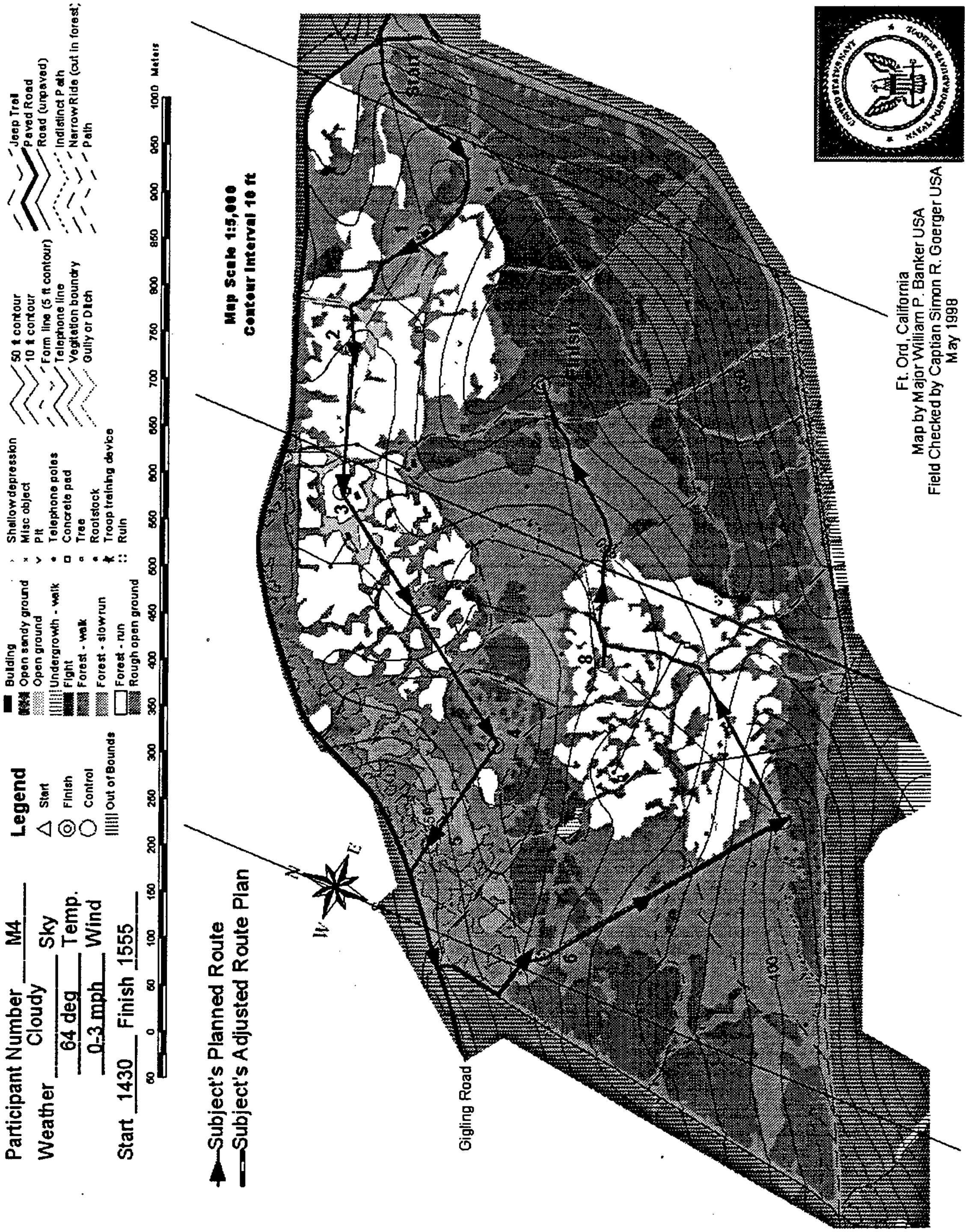


Figure N.22. M4 Planned Route

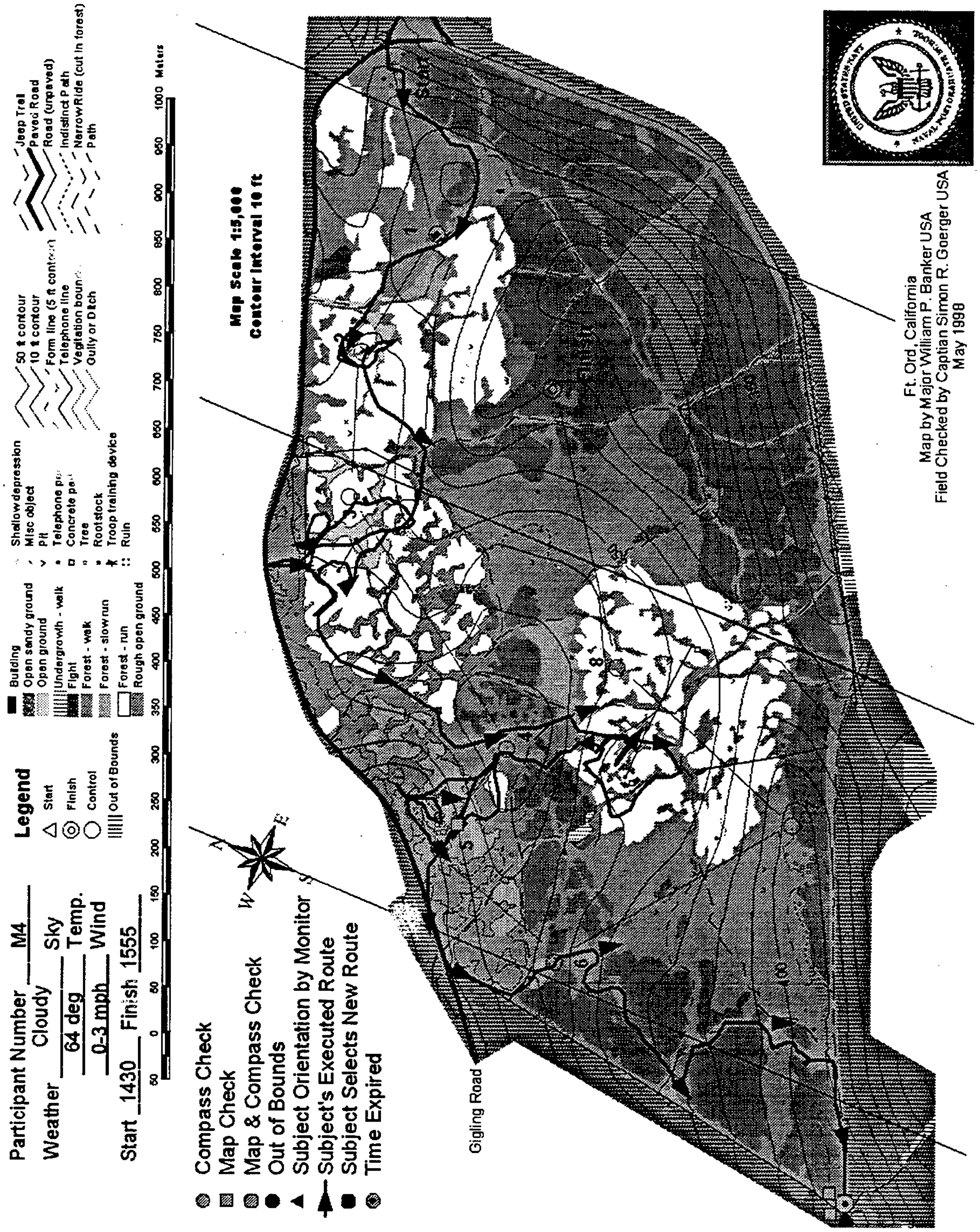


Figure N.23. M4 Executed Route

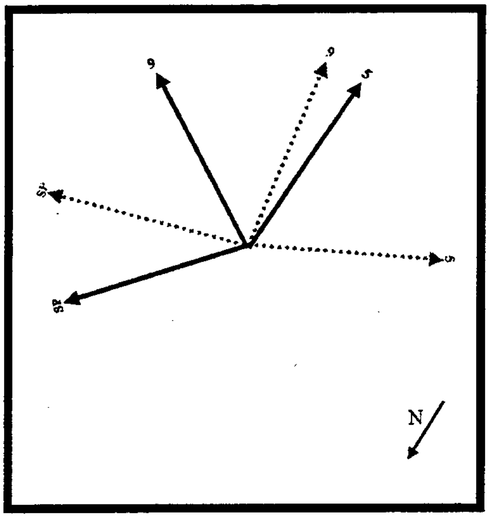


Figure N.24. M4 Wheel Test CP # 2

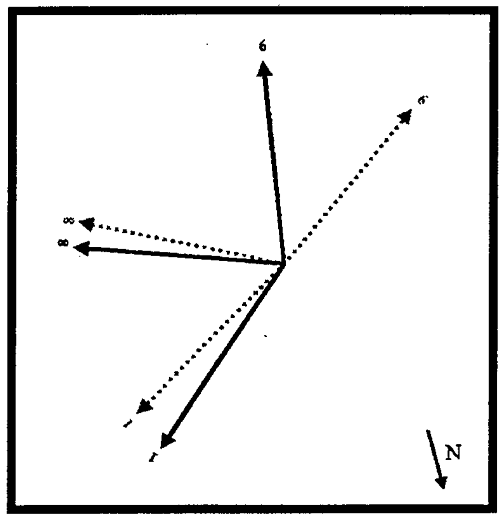


Figure N.25. M4 Wheel Test CP # 4

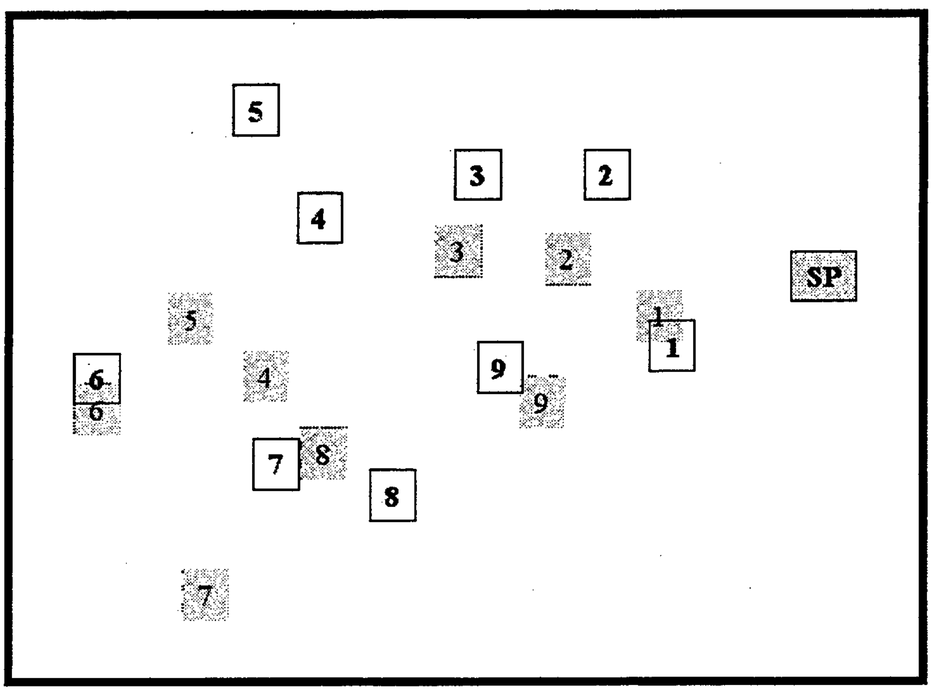


Figure N.26. M4 White Board Test

6. MAP PARTICIPANT NUMBER 5

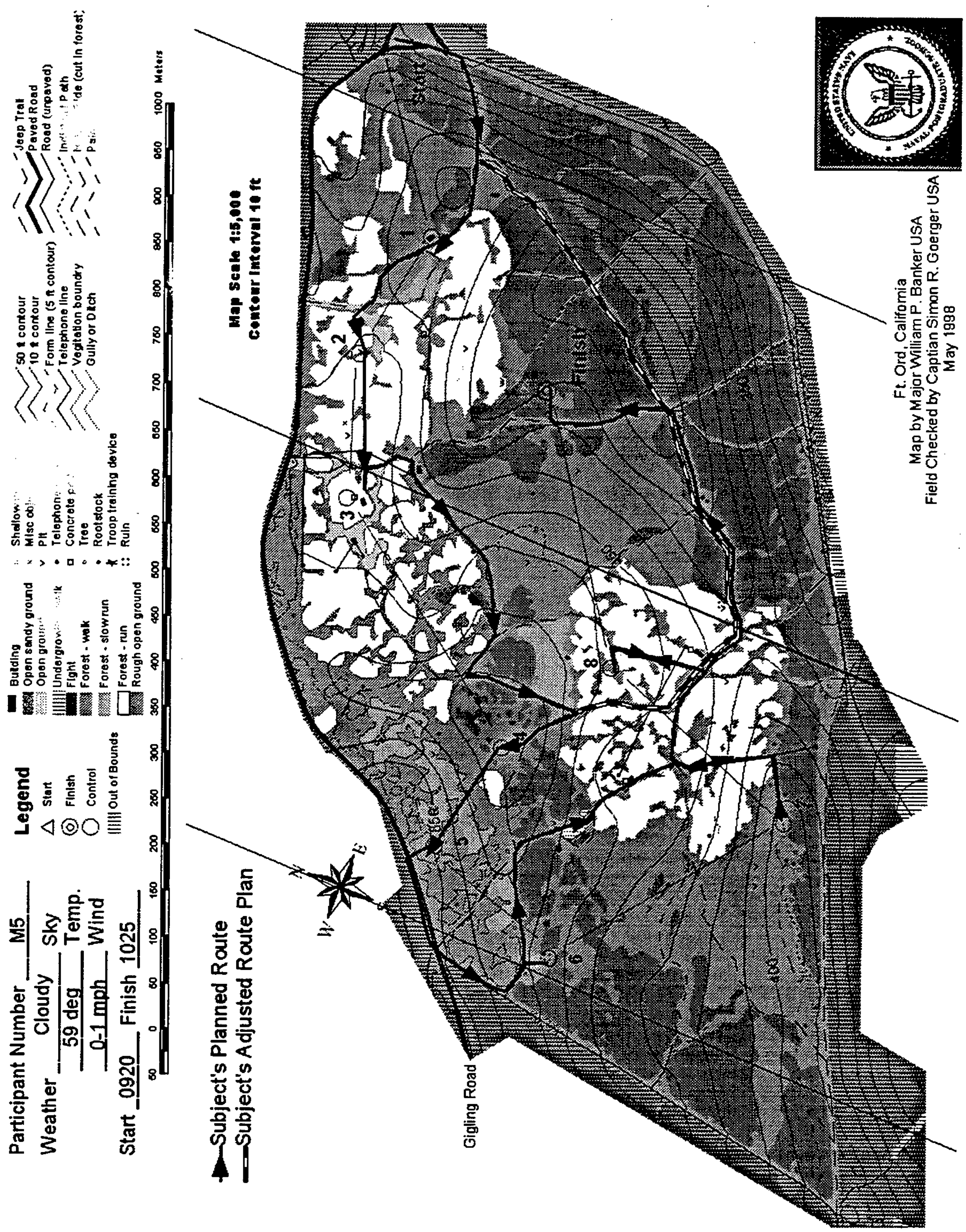


Figure N.27. M5 Planned Route

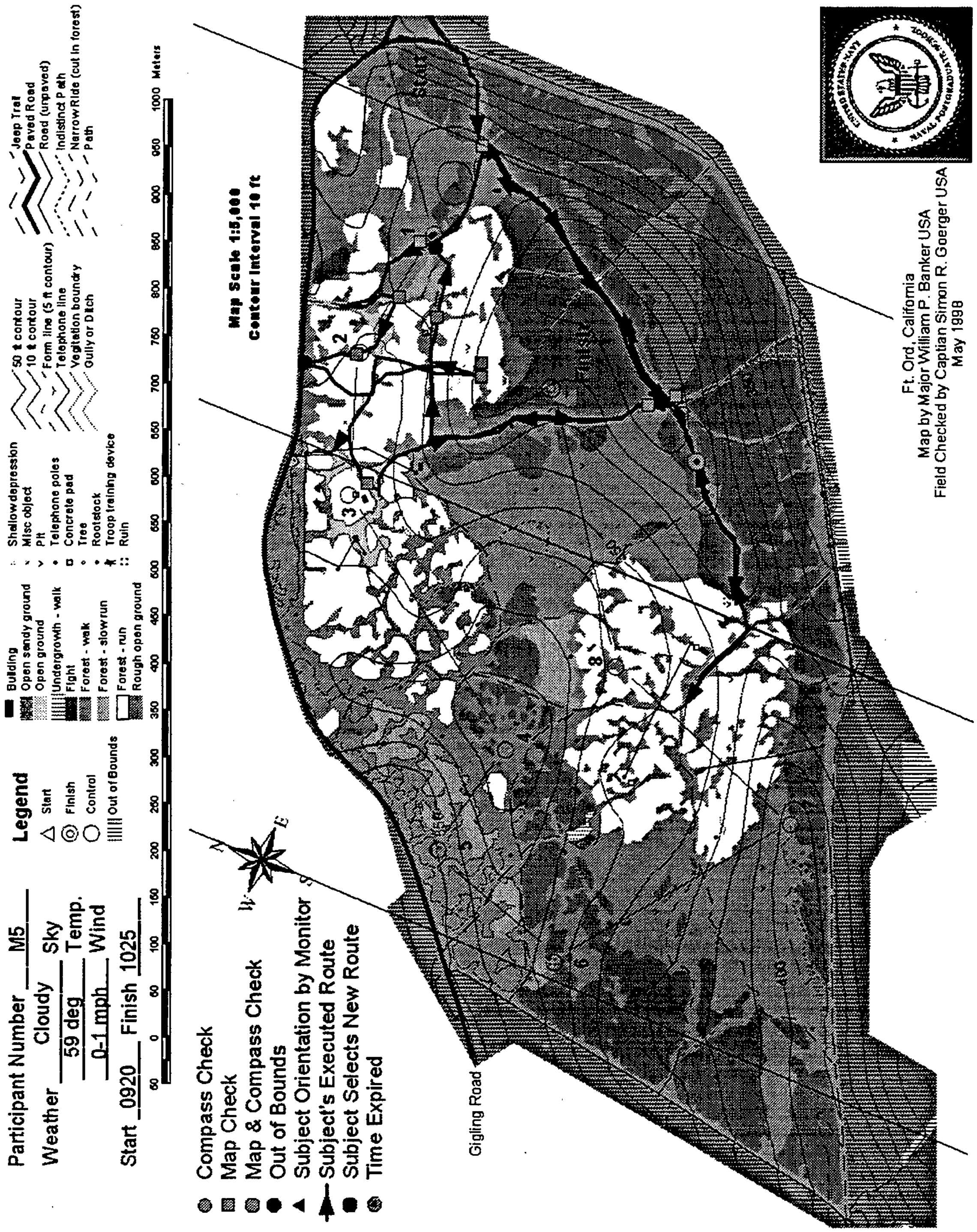


Figure N.28. M5 Executed Route

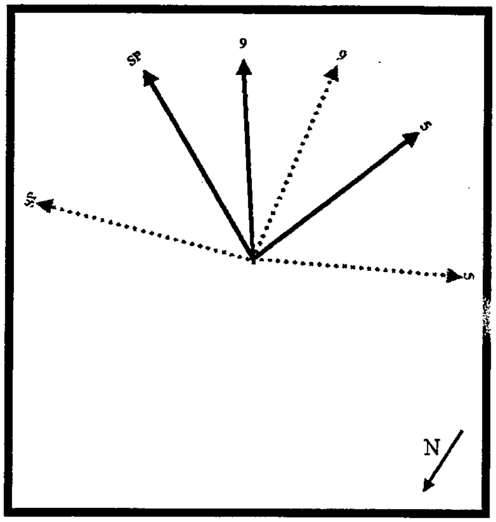


Figure N.29. M5 Wheel Test CP # 2

SUBJECT DID NOT
REACH CP #4;
NO DATA
COLLECTED

Figure N.30. M5 Wheel Test CP # 4

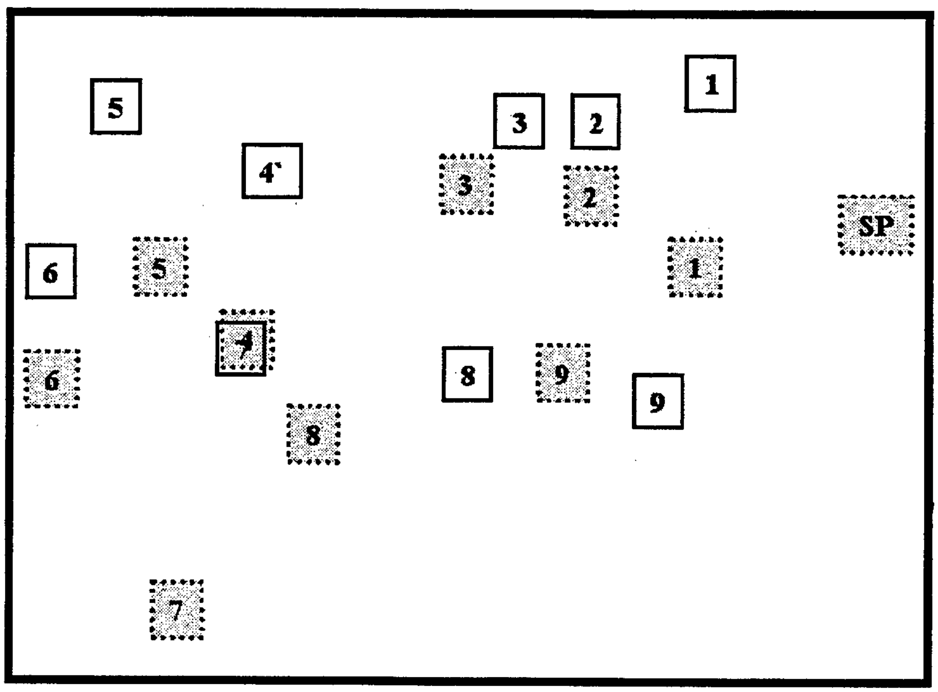


Figure N.31. M5 White Board Test

7. REAL WORLD PARTICIPANT NUMBER 1

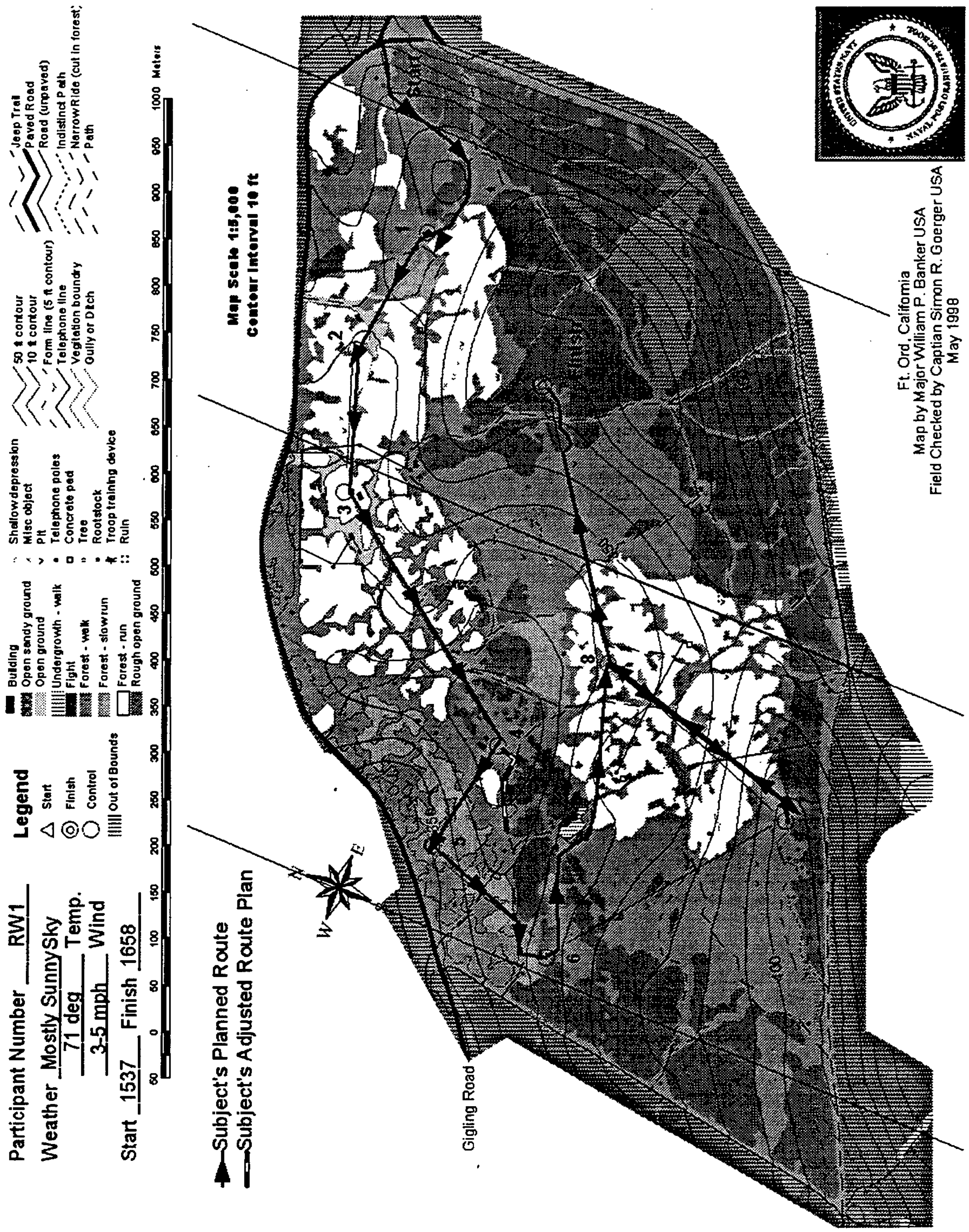


Figure N.32. RW1 Planned Route

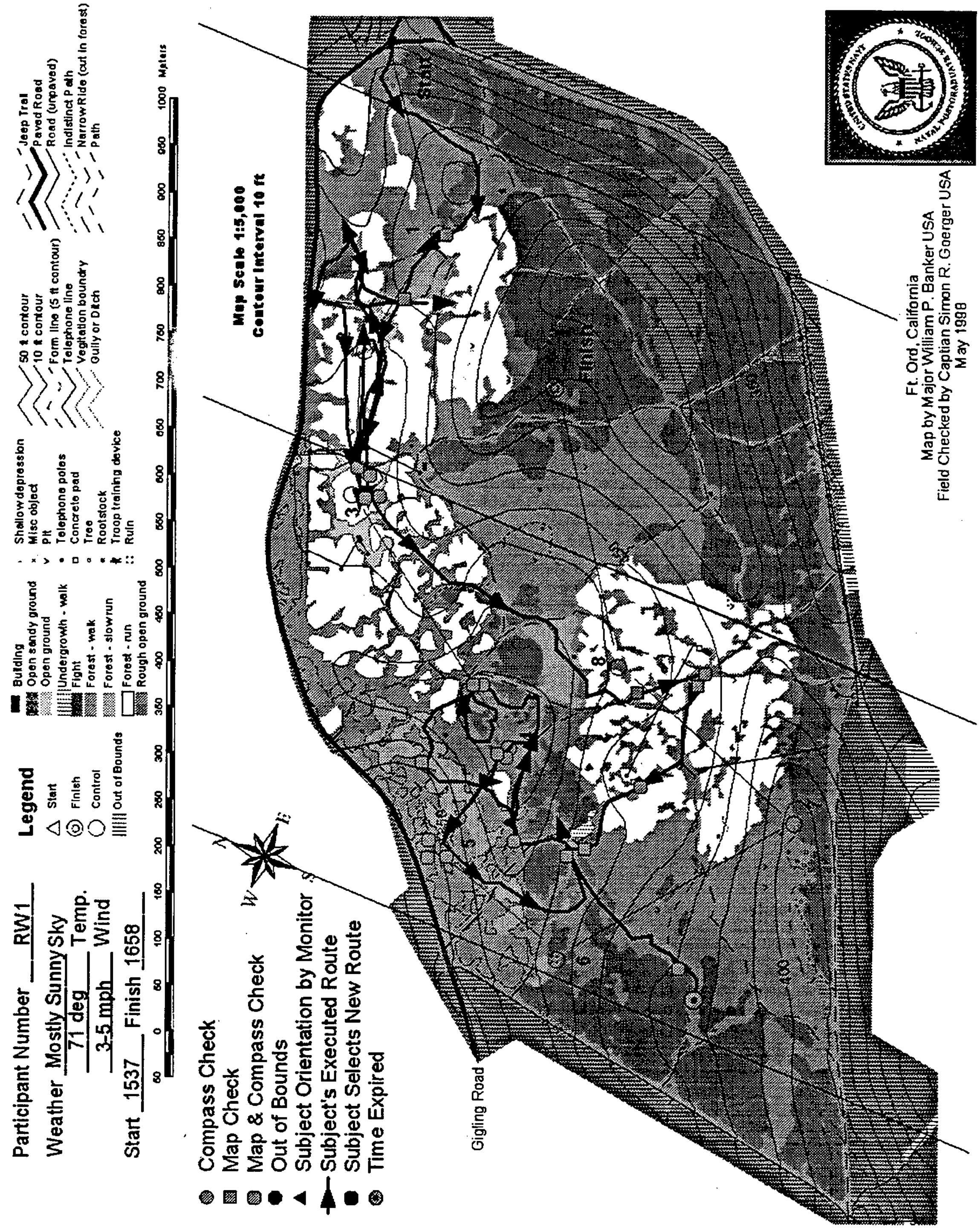


Figure N.33. RW1 Executed Route

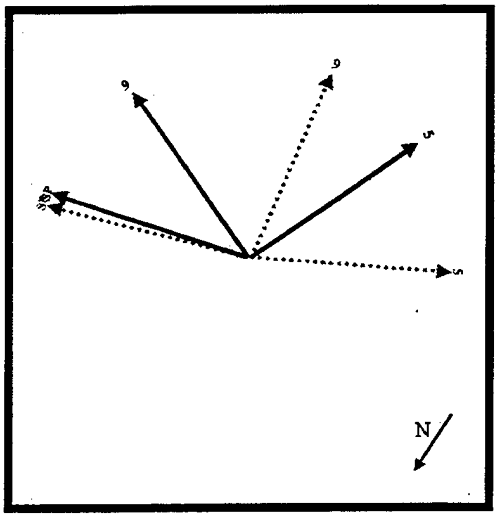


Figure N.34. RW1 Wheel Test CP # 2

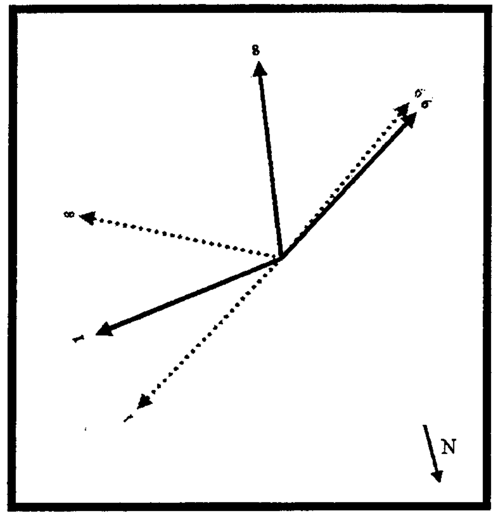


Figure N.35. RW1 Wheel Test CP # 4

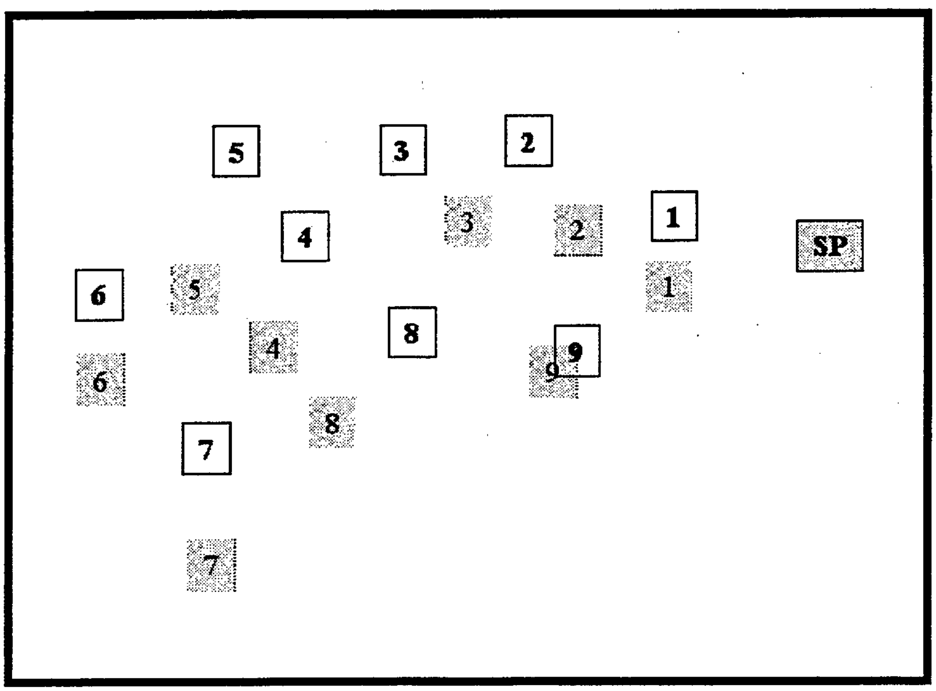


Figure N.36. RW1 White Board Test

8. REAL WORLD PARTICIPANT NUMBER 2

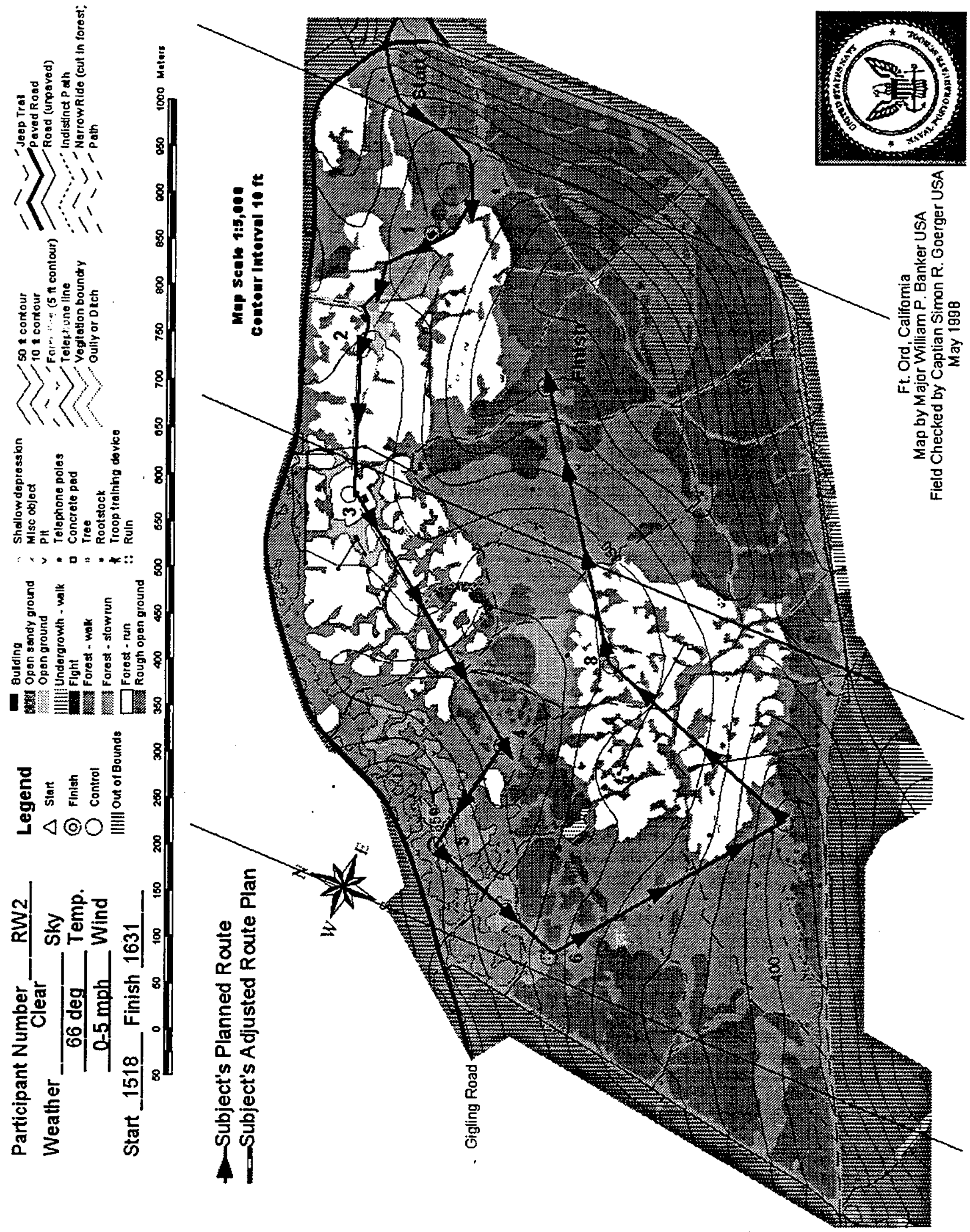


Figure N.37. RW2 Planned Route

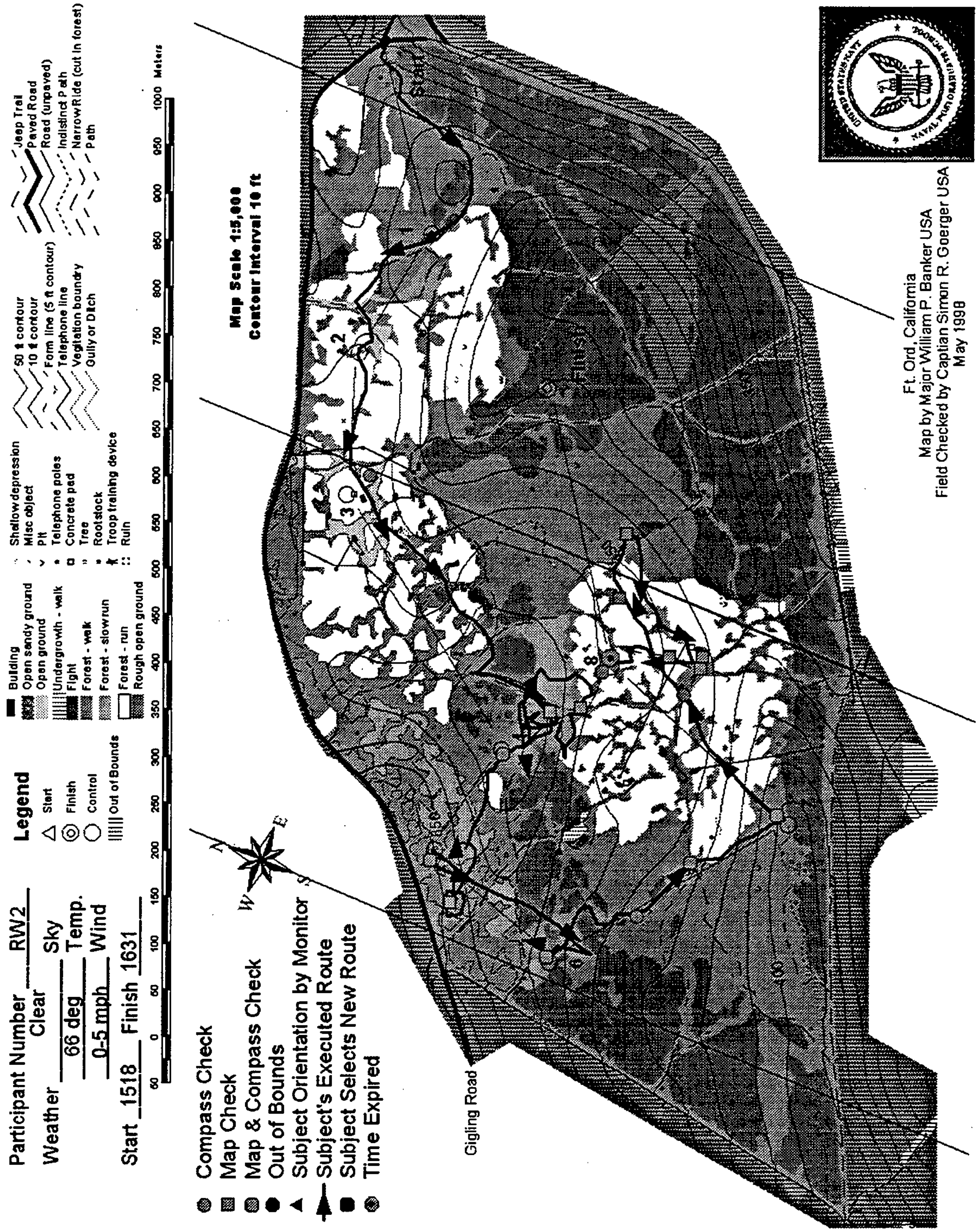


Figure N.38. RW2 Executed Route

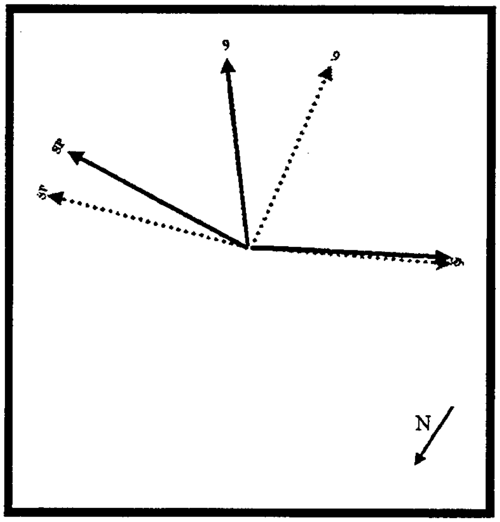


Figure N.39. RW2 Wheel Test CP # 2

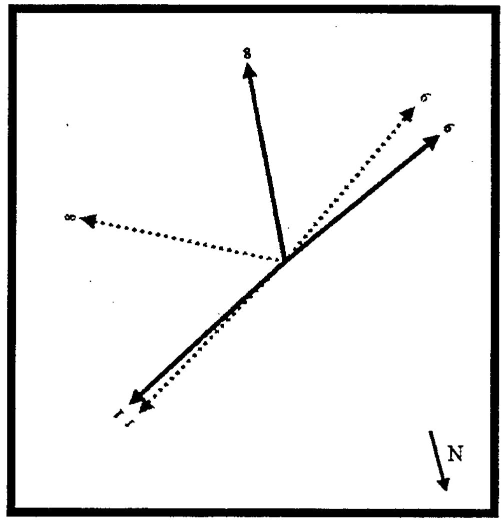


Figure N.40. RW2 Wheel Test CP # 4

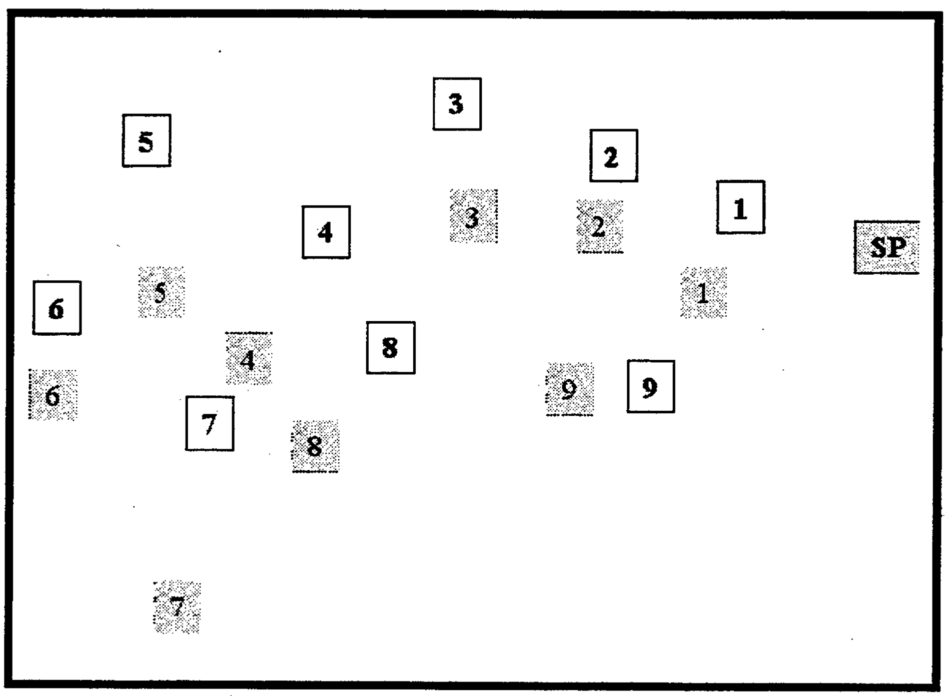


Figure N.41. RW2 White Board Test

9. REAL WORLD PARTICIPANT NUMBER 3

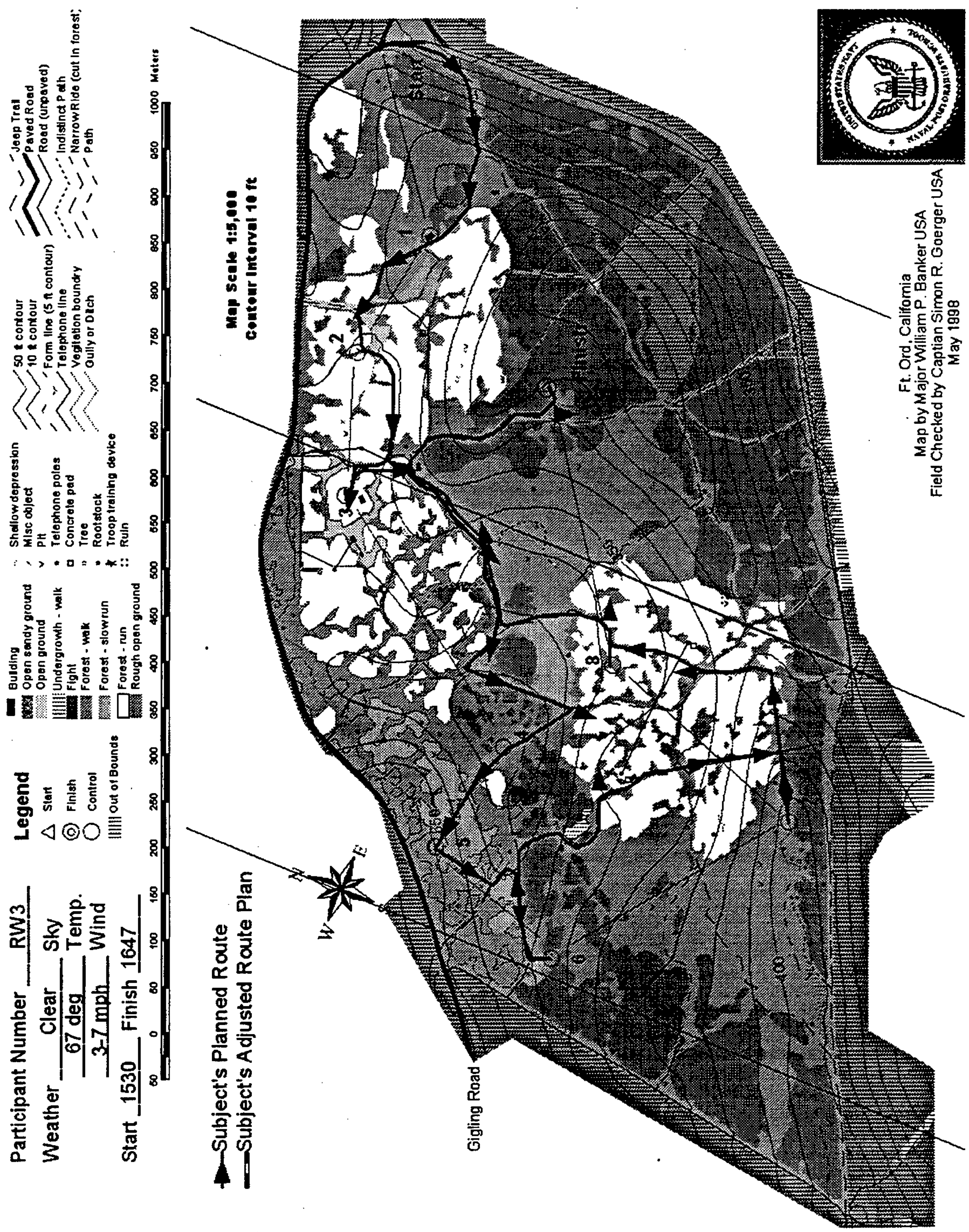


Figure N.42. RW3 Planned Route

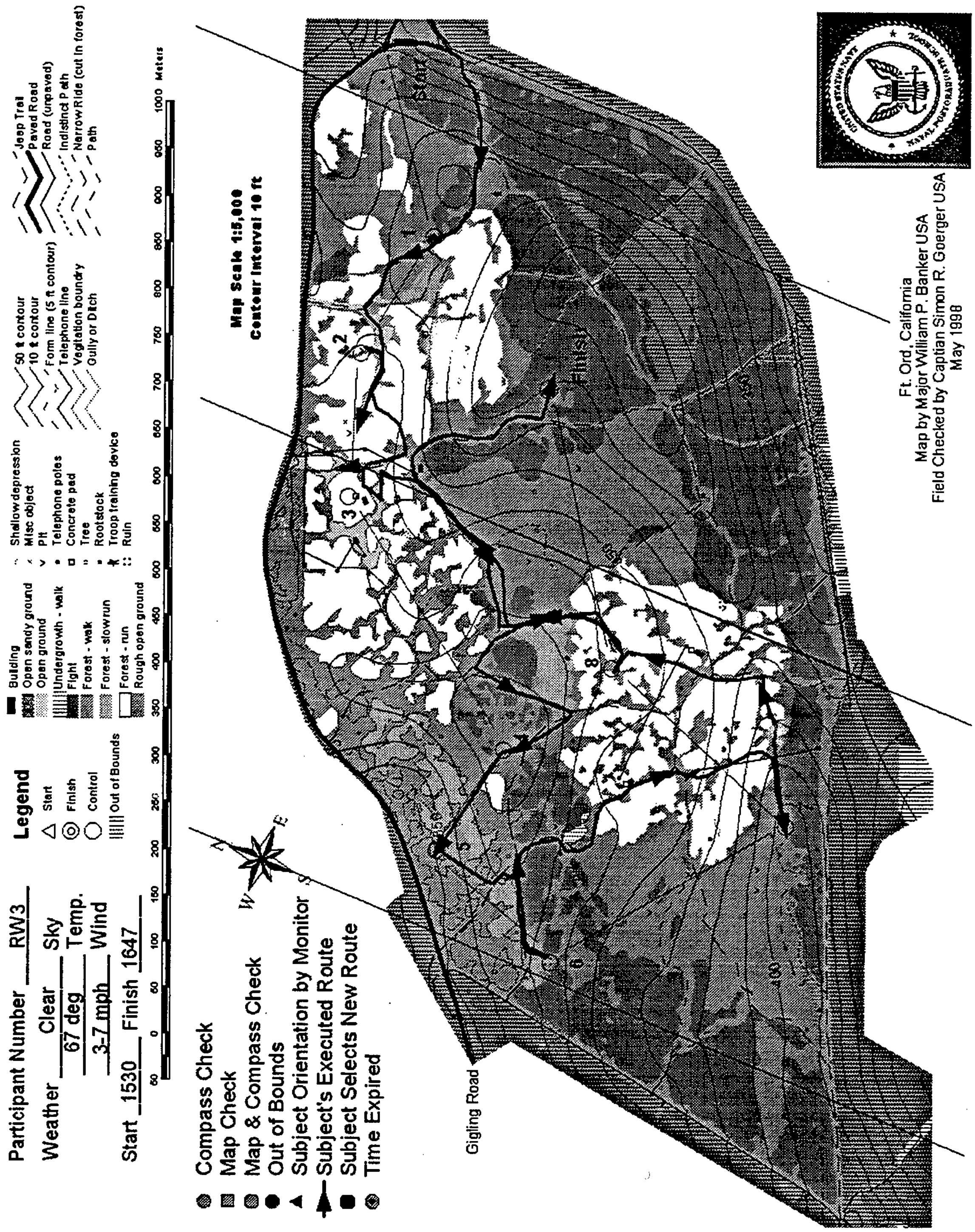


Figure N.43. RW3 Executed Route

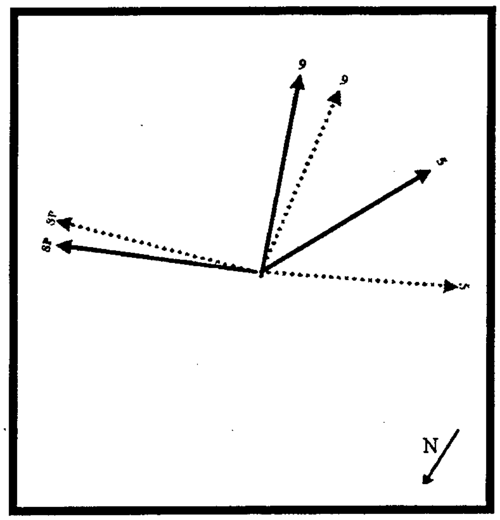


Figure N.44. RW3 Wheel Test CP # 2

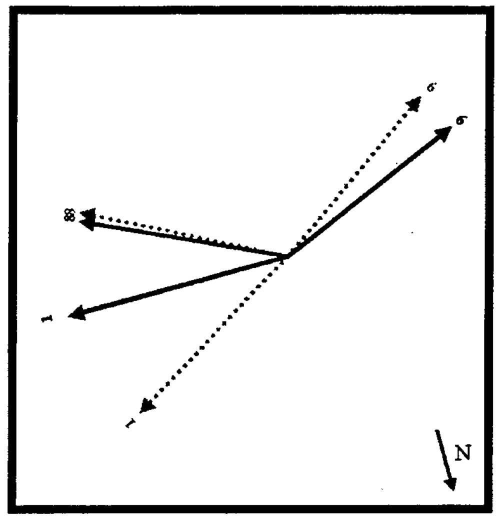


Figure N.45. RW3 Wheel Test CP # 4

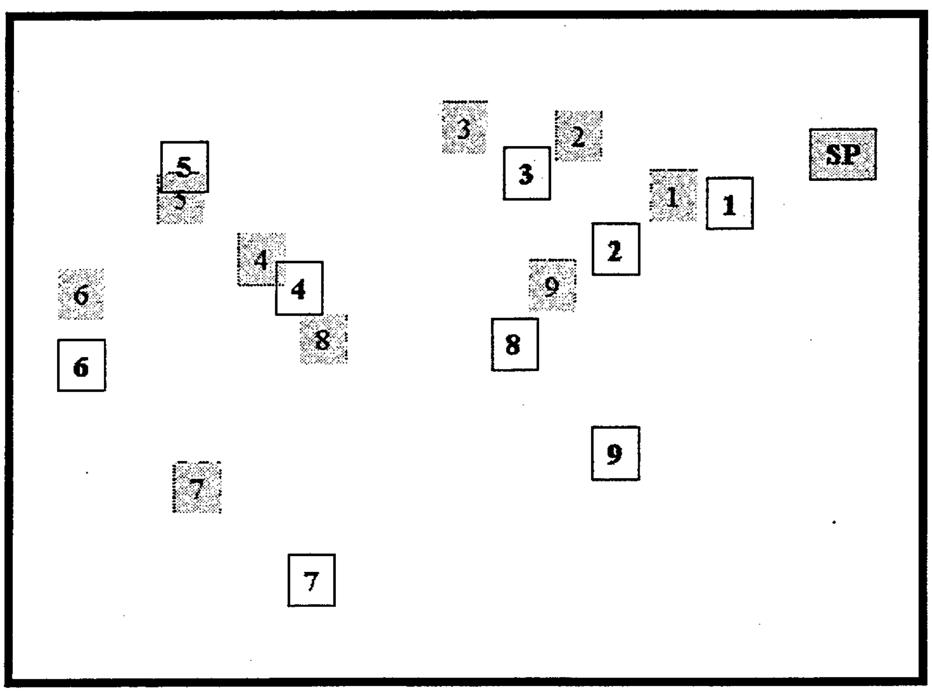


Figure N.46. RW3 White Board Test

10. REAL WORLD PARTICIPANT NUMBER 4

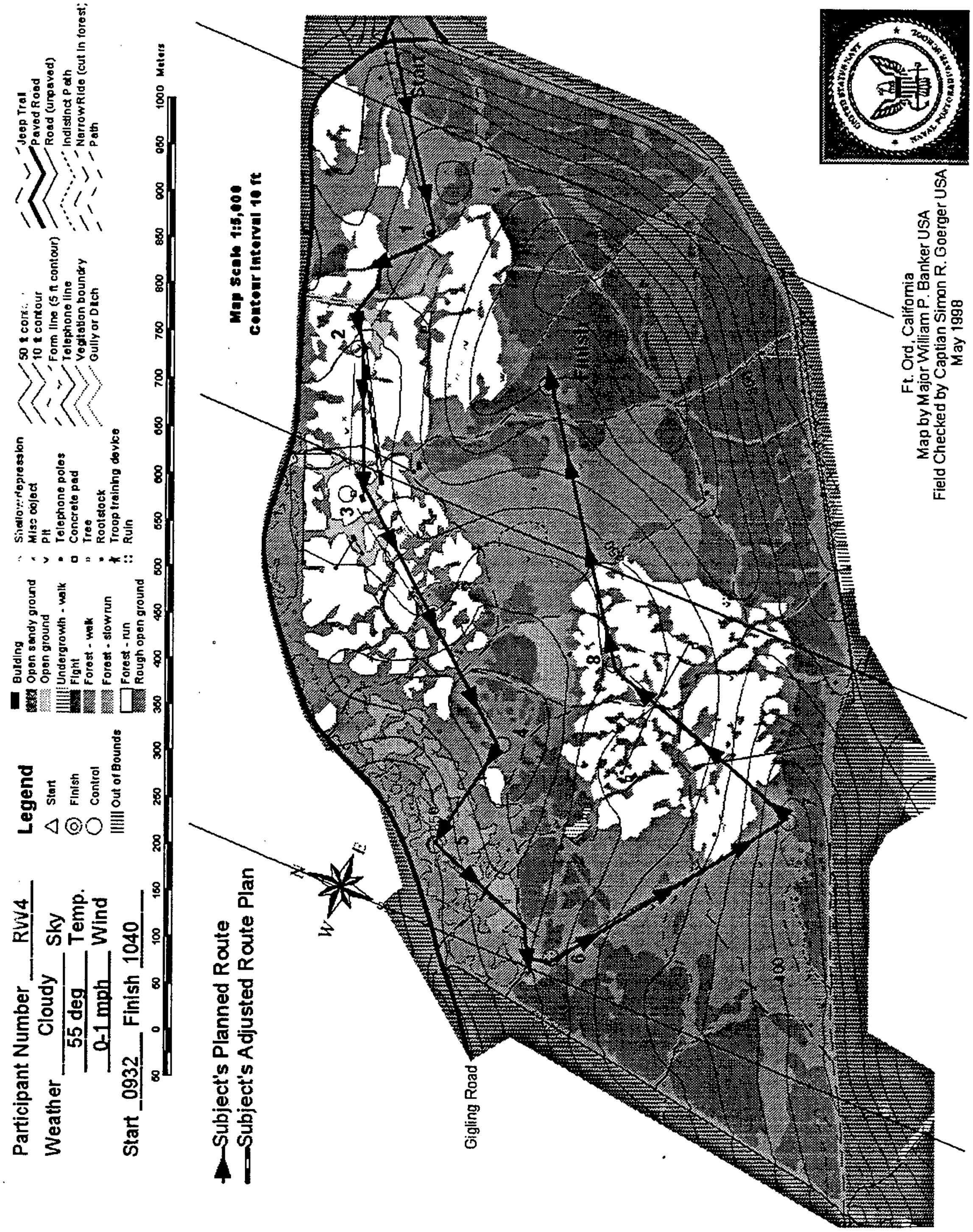


Figure N.47. RW4 Planned Route

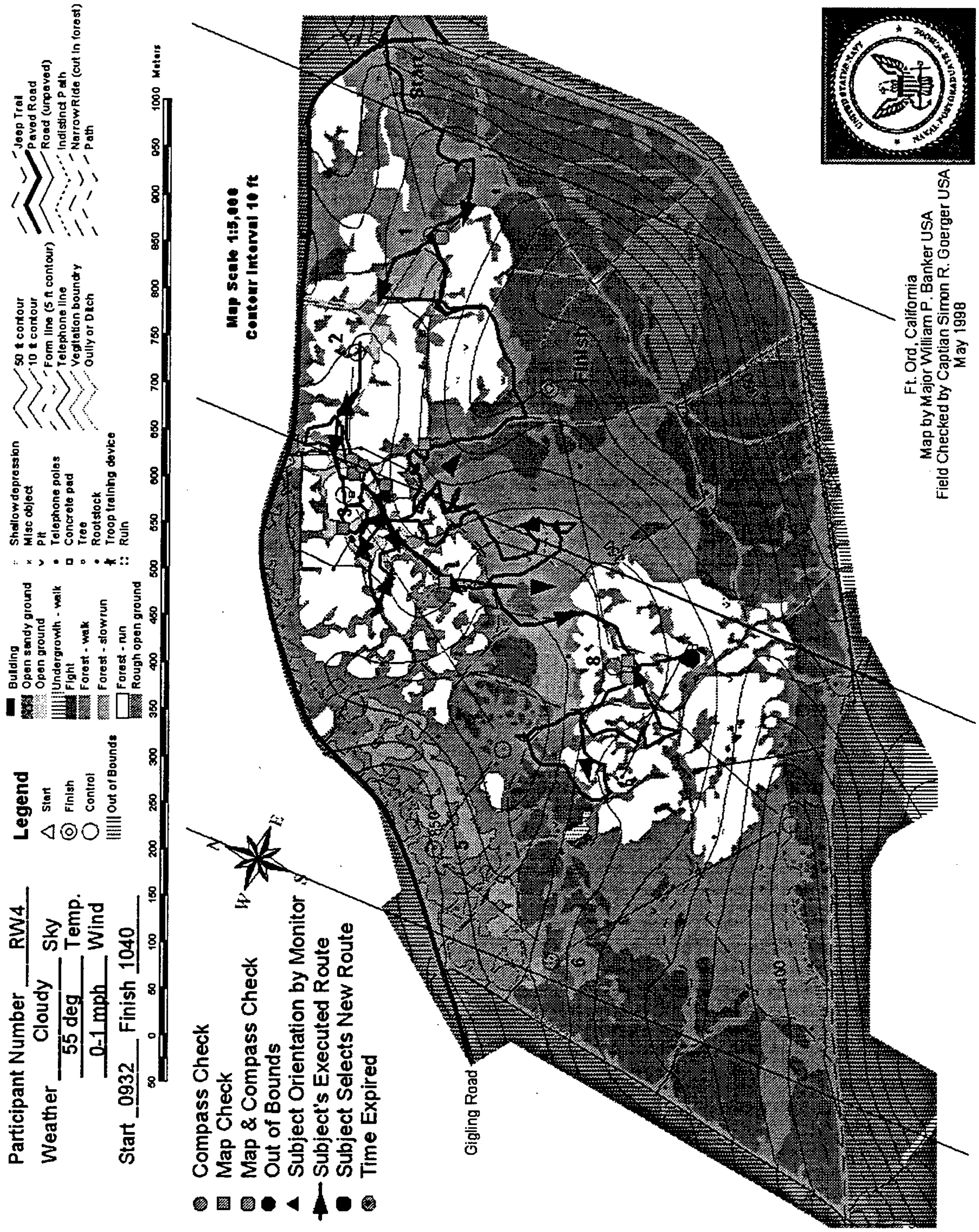


Figure N.48. RW4 Executed Route

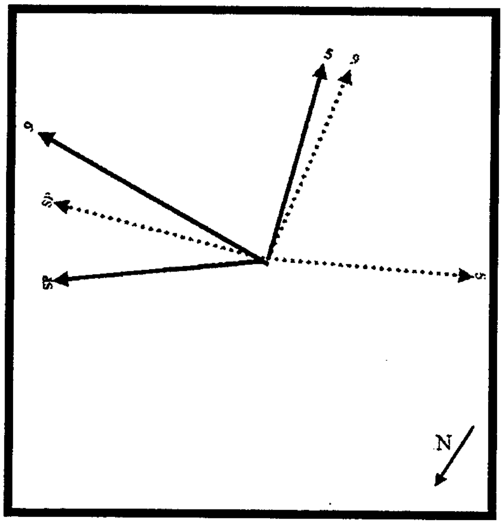


Figure N.49. RW4 Wheel Test CP # 2

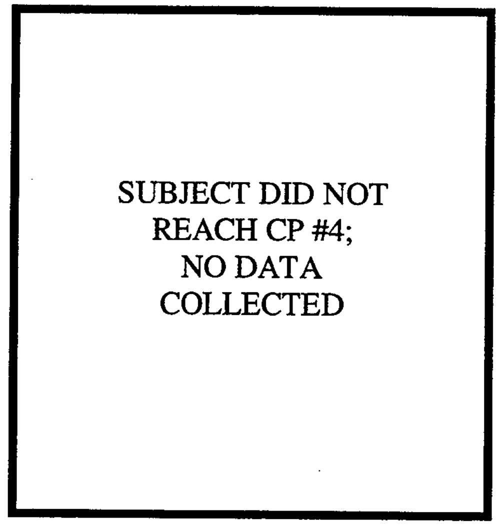


Figure N.50. RW4 Wheel Test CP # 4

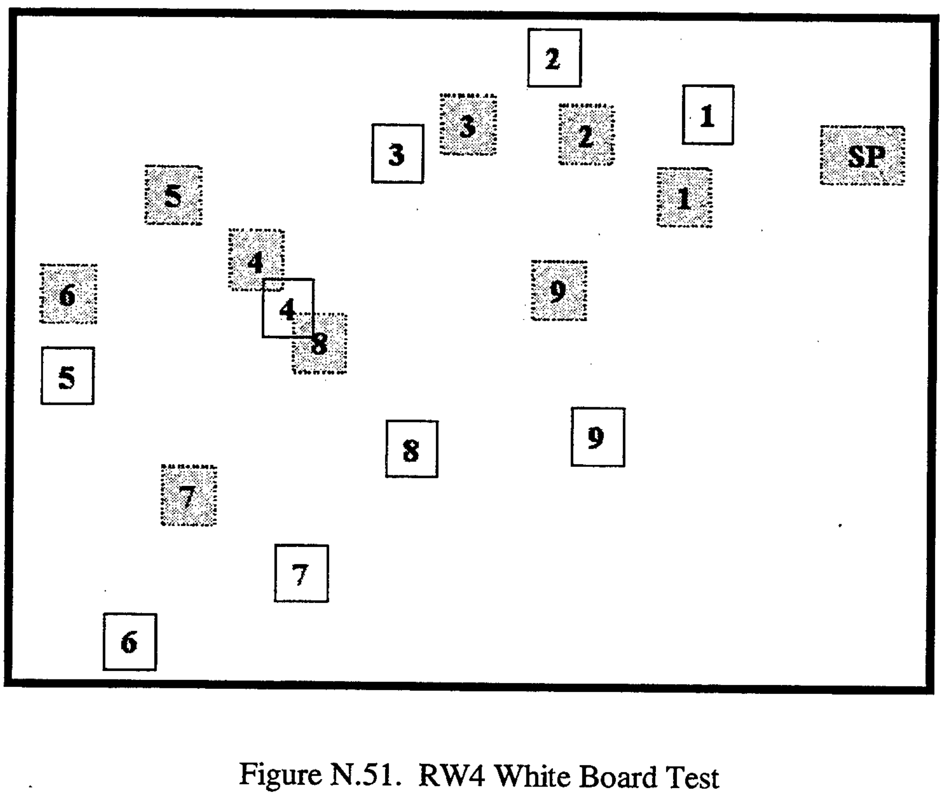


Figure N.51. RW4 White Board Test

11. REAL WORLD PARTICIPANT NUMBER 5

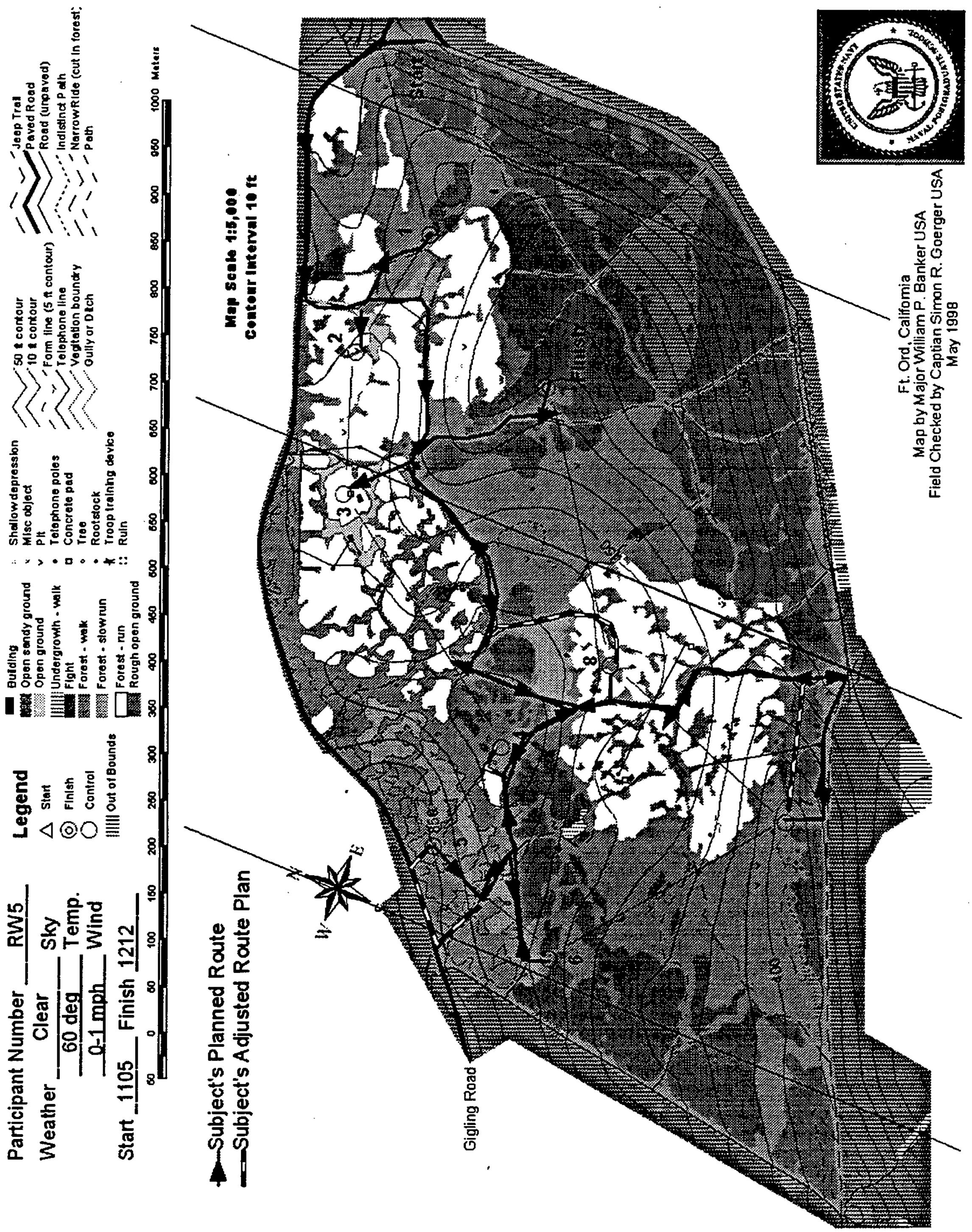


Figure N.52. RW5 Planned Route

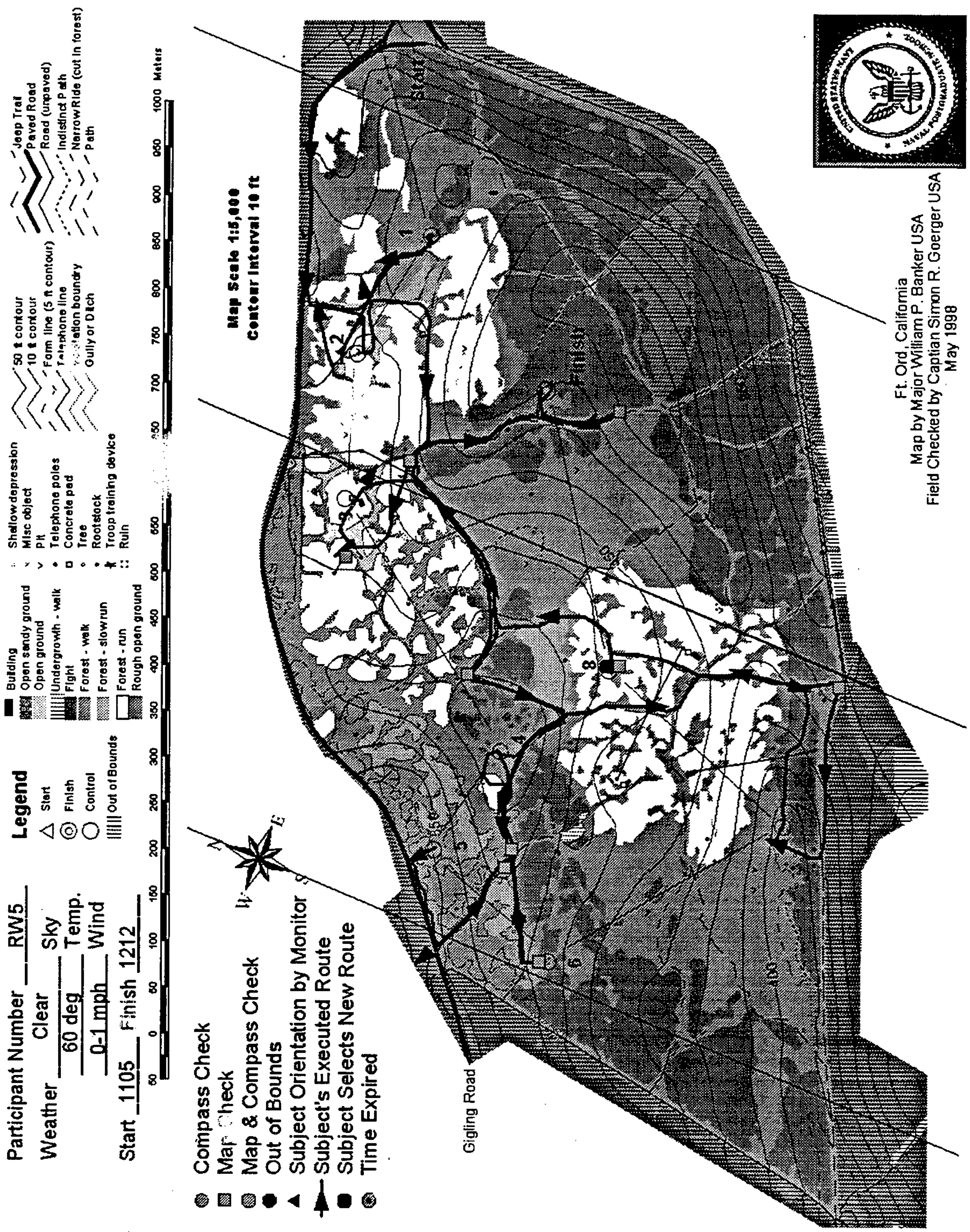


Figure N.53. RW5 Executed Route

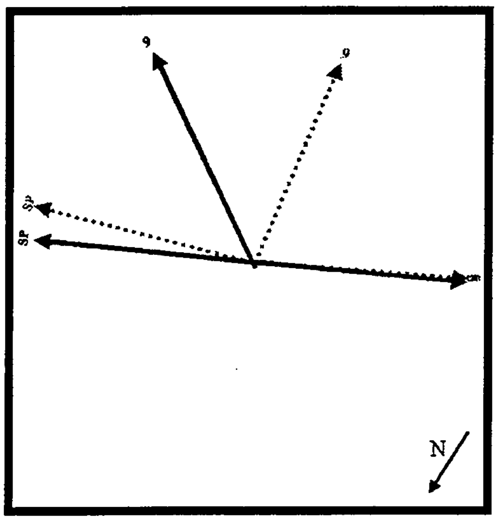


Figure N.54. RW5 Wheel Test CP # 2

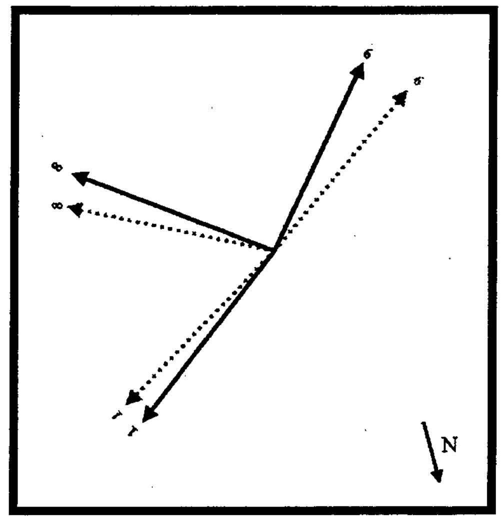


Figure N.55. RW5 Wheel Test CP # 4

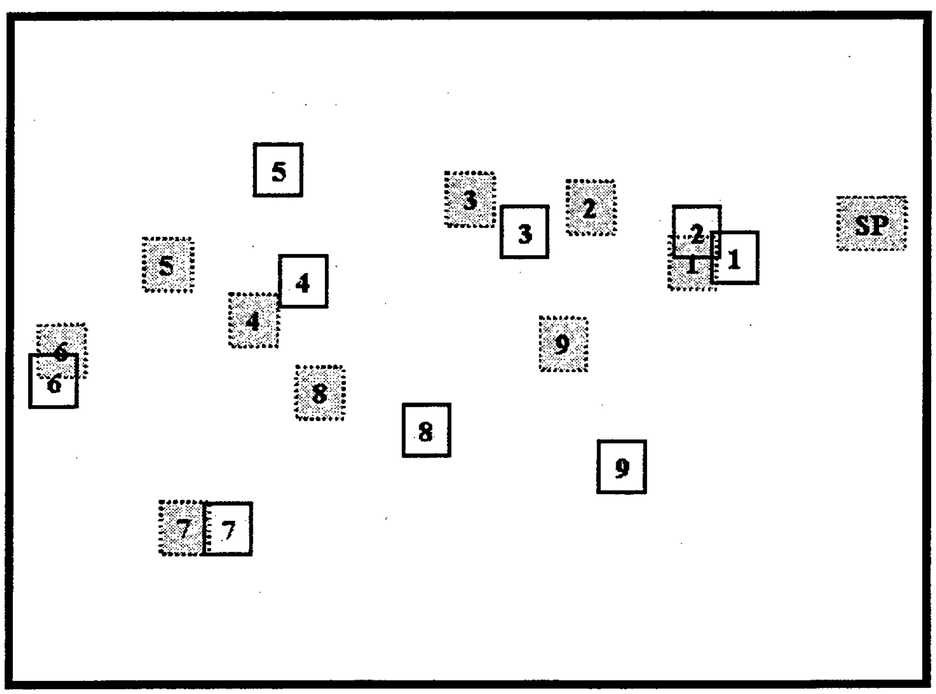


Figure N.56. RW5 White Board Test

12. VIRTUAL ENVIRONMENT PARTICIPANT NUMBER 1

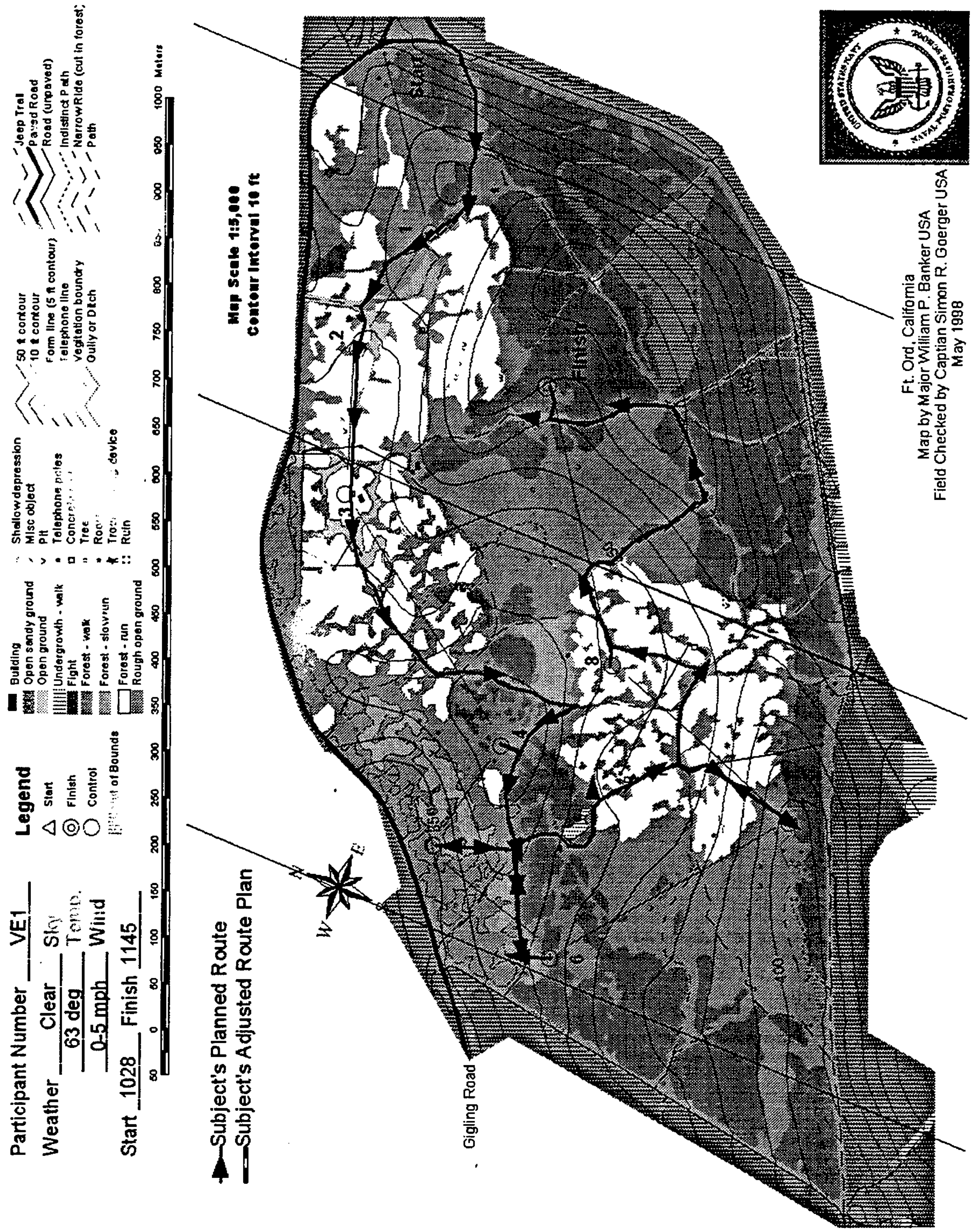


Figure N.57. VE1Planned Route

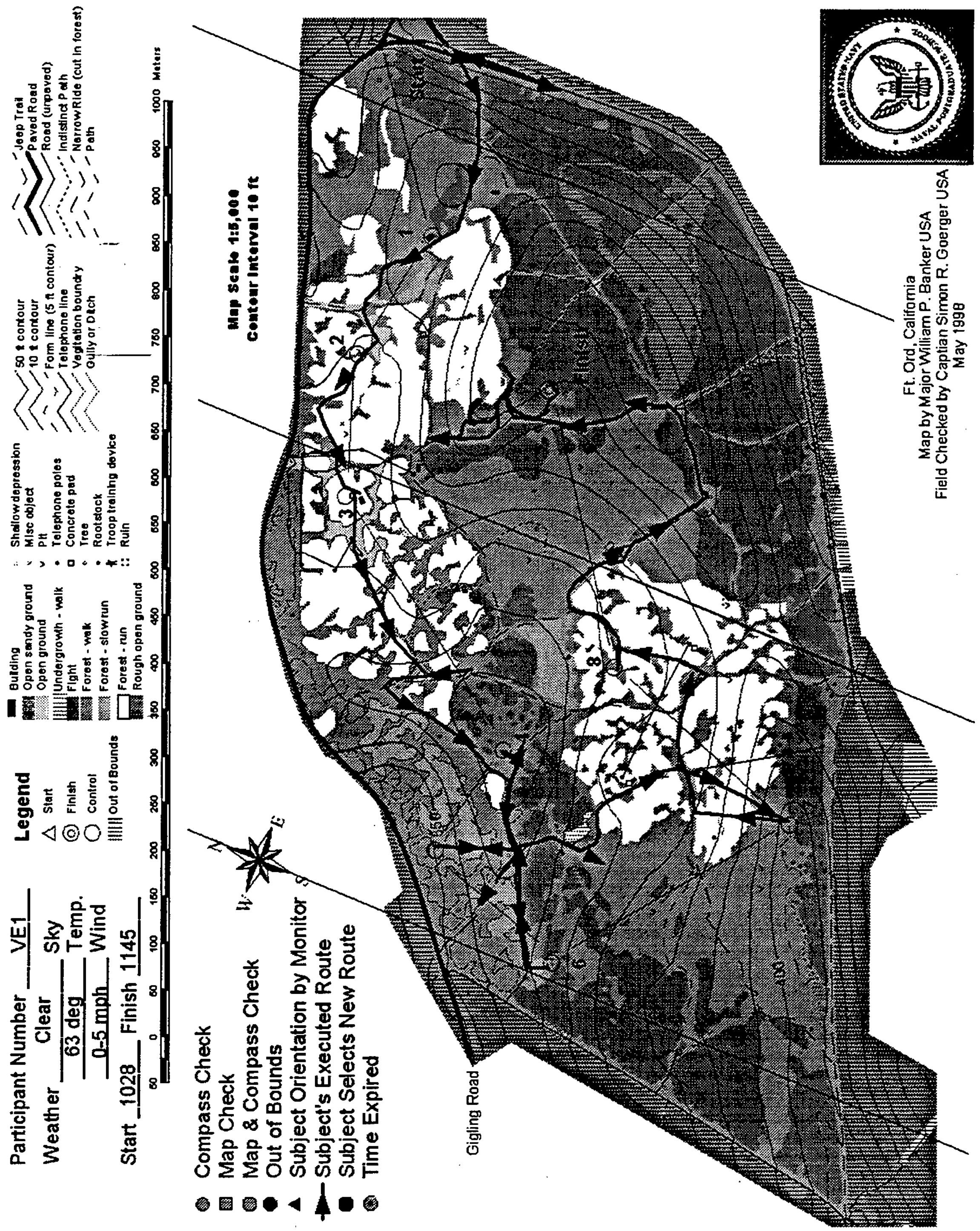


Figure N.58. VE1 Executed Route

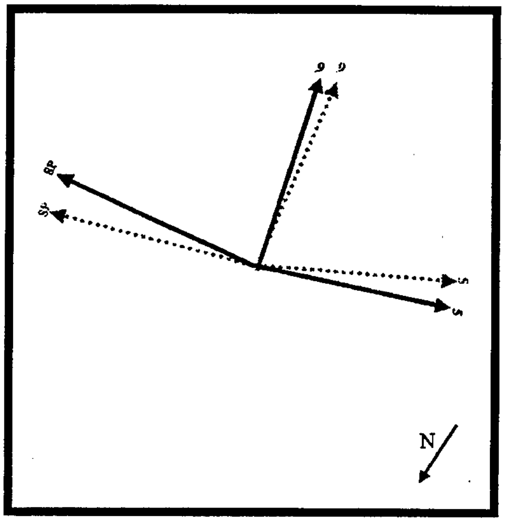


Figure N.59. VE1 Wheel Test CP # 2

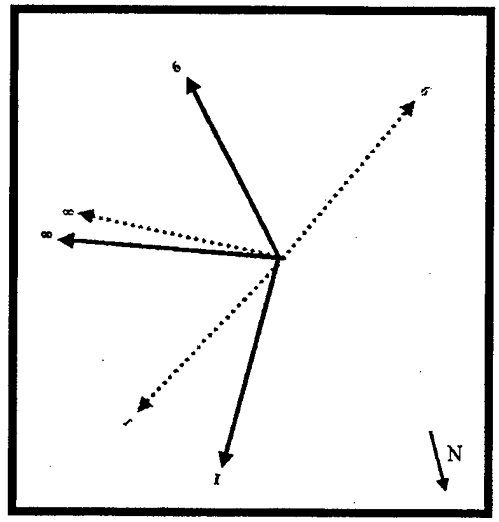


Figure N.60. VE1 Wheel Test CP # 4

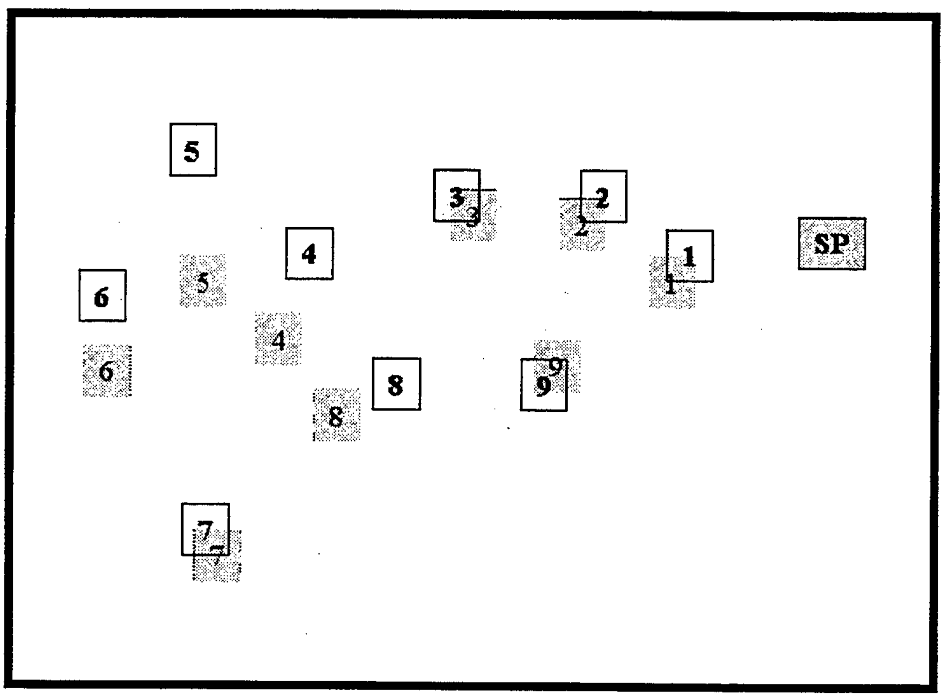


Figure N.61. VE1 White Board Test

13. VIRTUAL ENVIRONMENT PARTICIPANT NUMBER 2

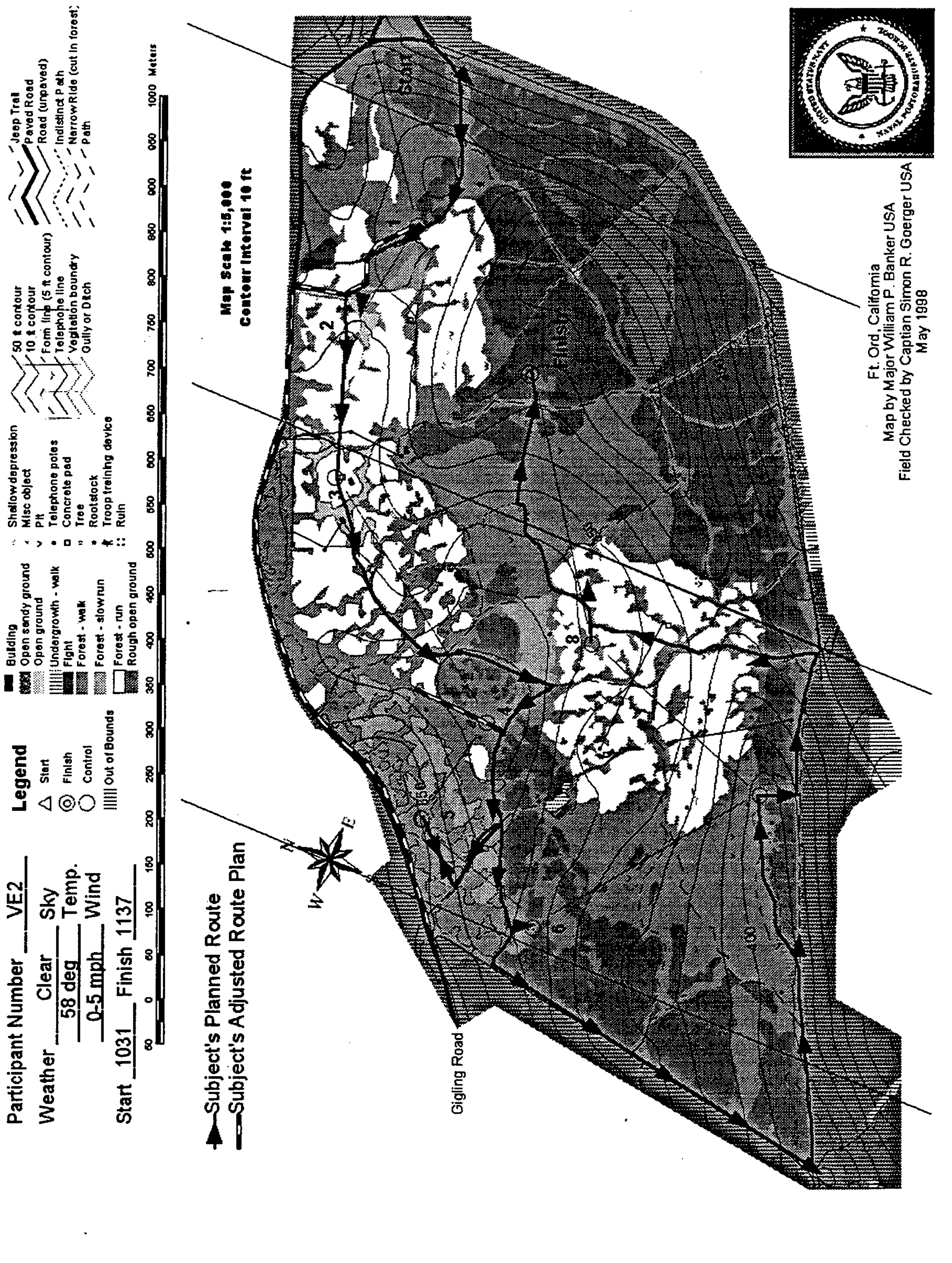


Figure N.62. VE2 Planned Route

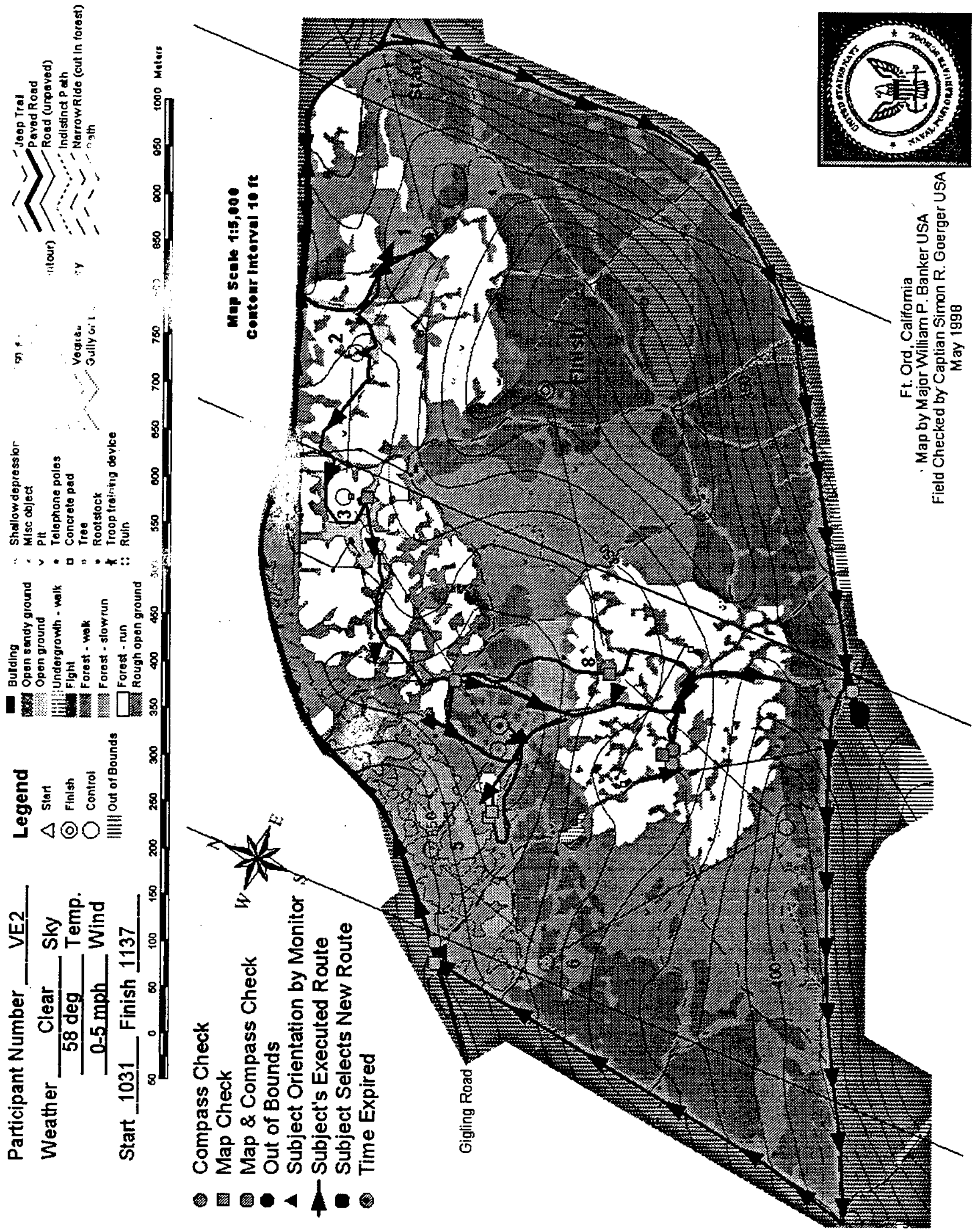


Figure N.63. VE2 Executed Route

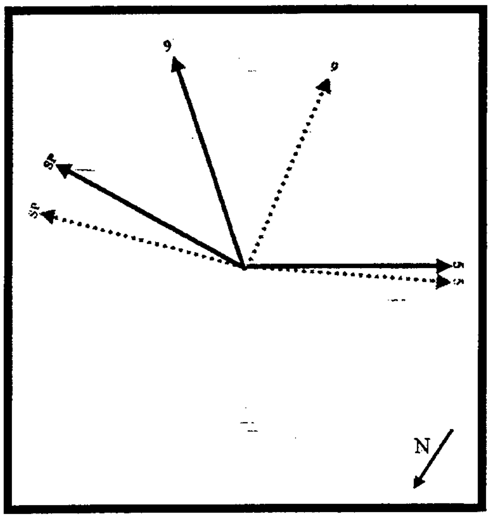


Figure N.64. VE2 Wheel Test CP # 2

SUBJECT DID NOT
REACH CP #4;
NO DATA
COLLECTED

Figure N.65. VE2 Wheel Test CP # 4

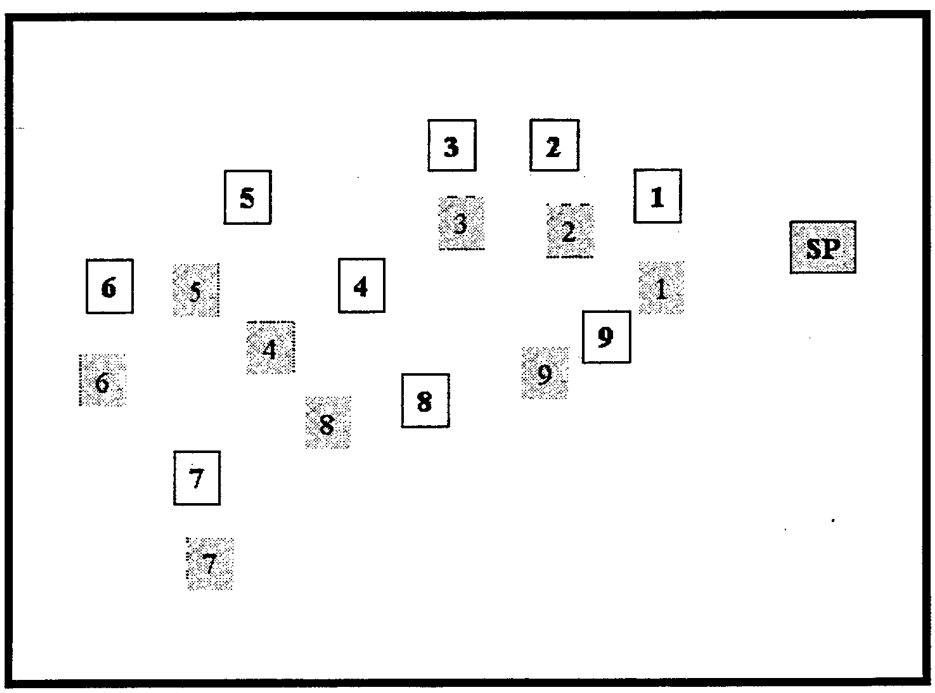


Figure N.66. VE2 White Board Test

14. VIRTUAL ENVIRONMENT PARTICIPANT NUMBER 3

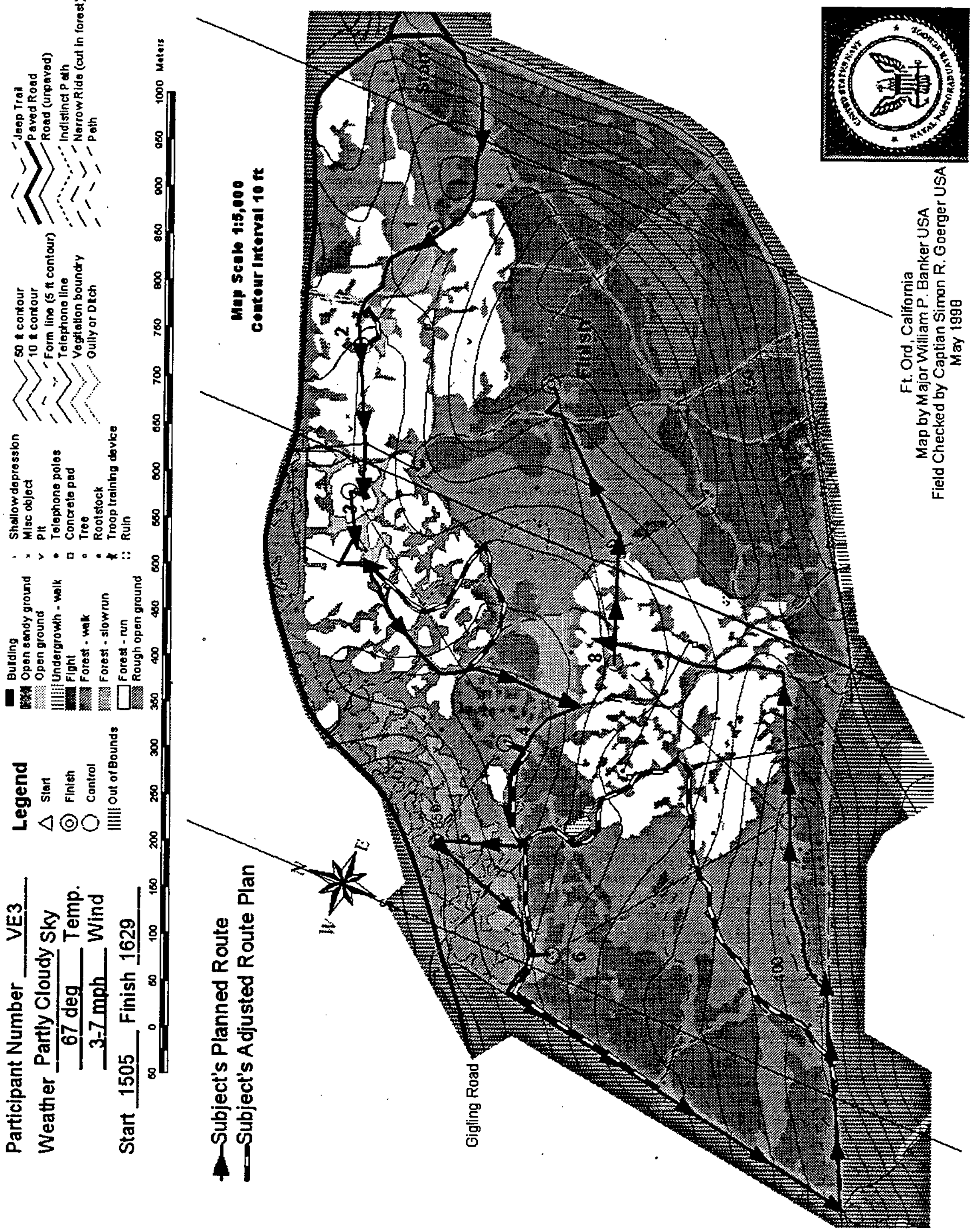


Figure N.67. VE3 Planned Route

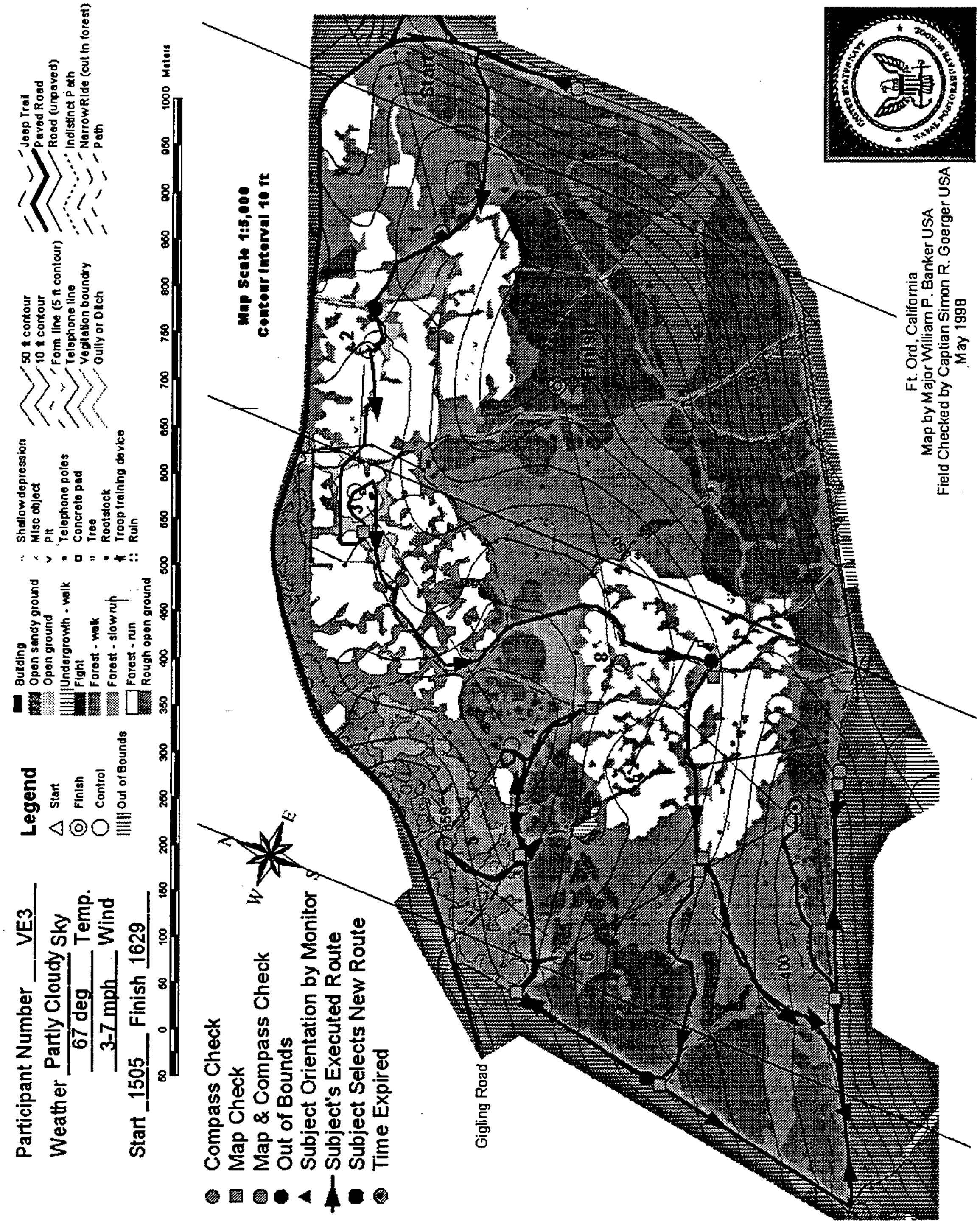


Figure N.68. VE3 Executed Route

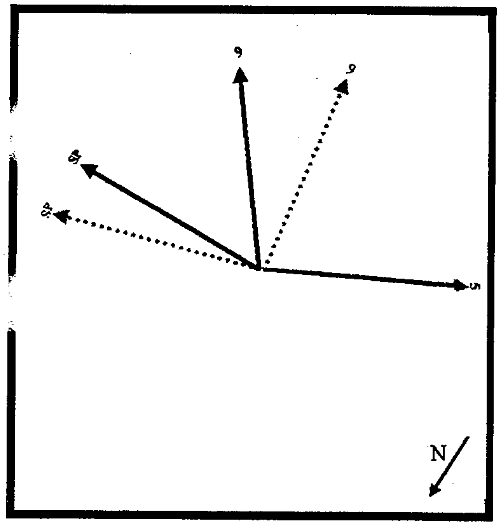


Figure N.69. VE3 Wheel Test CP # 2

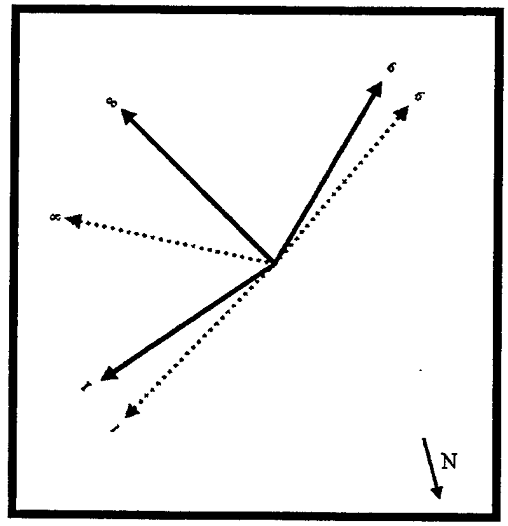


Figure N.70. VE3 Wheel Test CP # 4

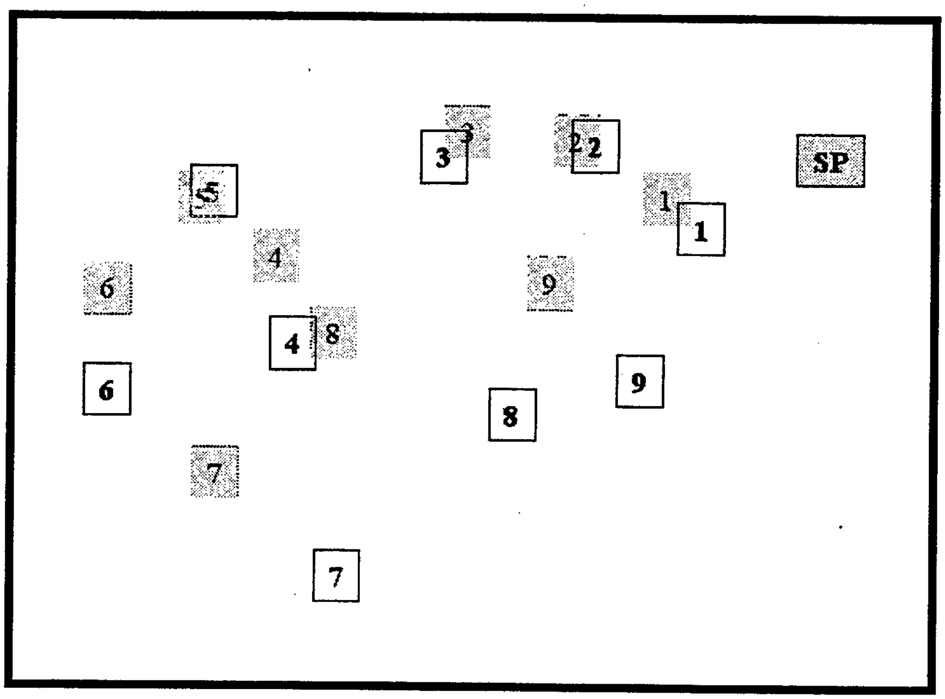


Figure N.71. VE3 White Board Test

15. VIRTUAL ENVIRONMENT PARTICIPANT NUMBER 4

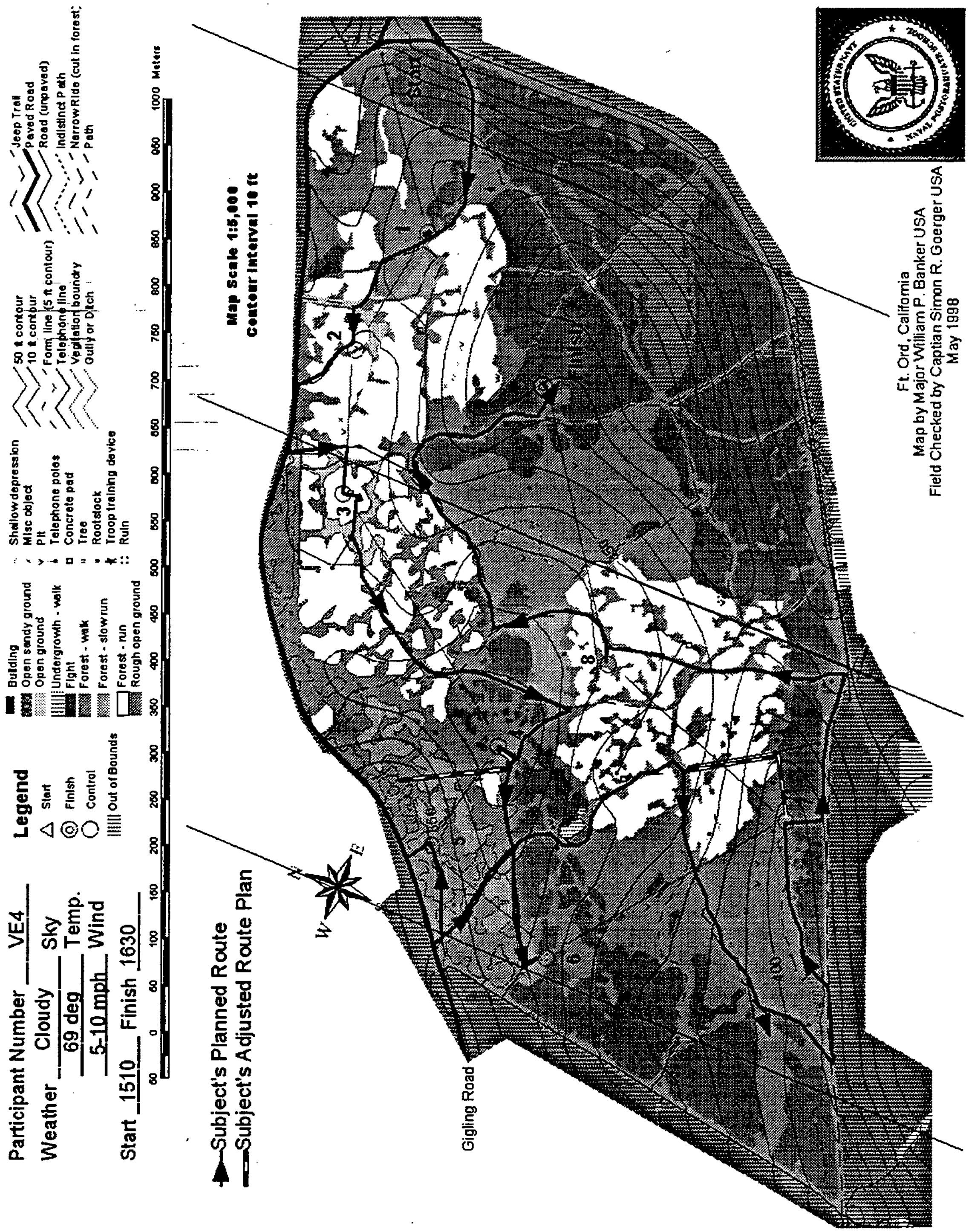


Figure N.72. VE4 Planned Route

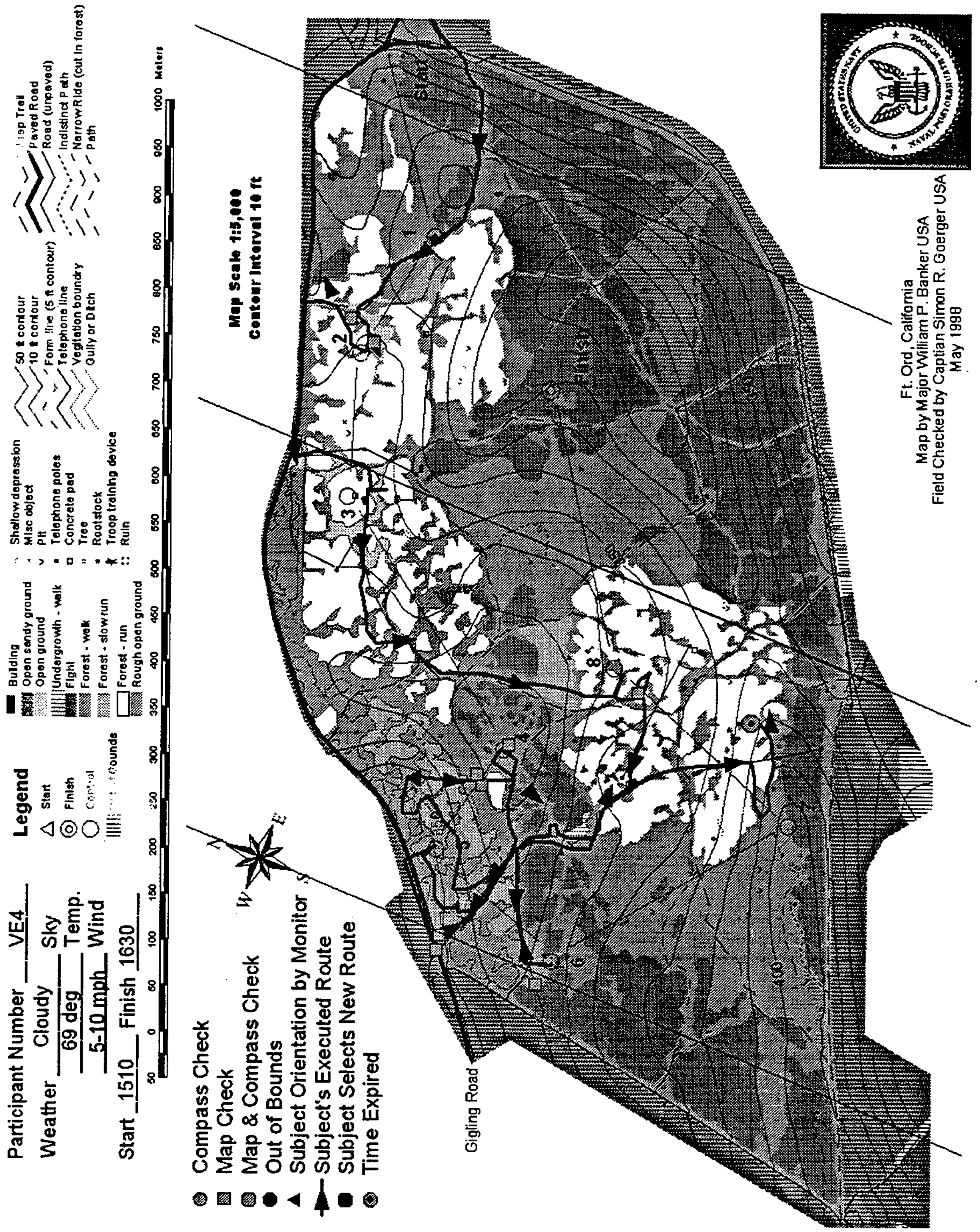


Figure N.73. VE4 Executed Route

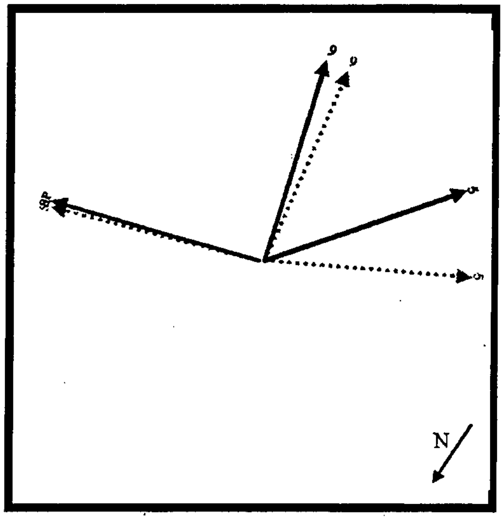


Figure N.74. VE4 Wheel Test CP # 2

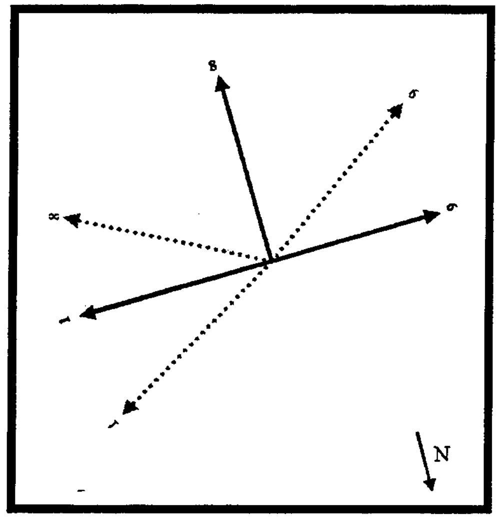


Figure N.75. VE4 Wheel Test CP # 4

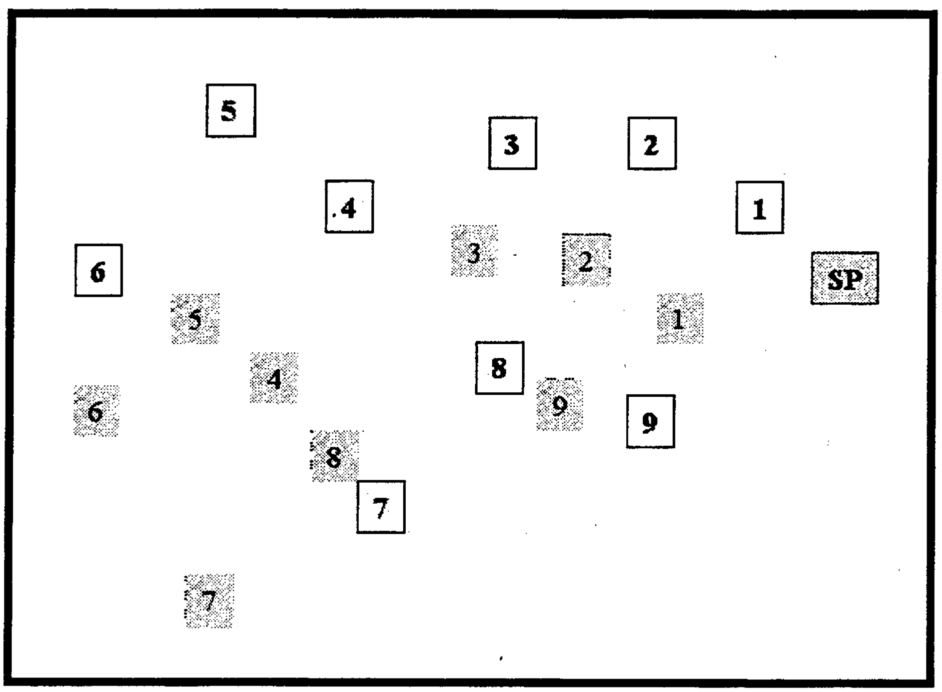


Figure N.76. VE4 White Board Test

16. VIRTUAL ENVIRONMENT PARTICIPANT NUMBER 5

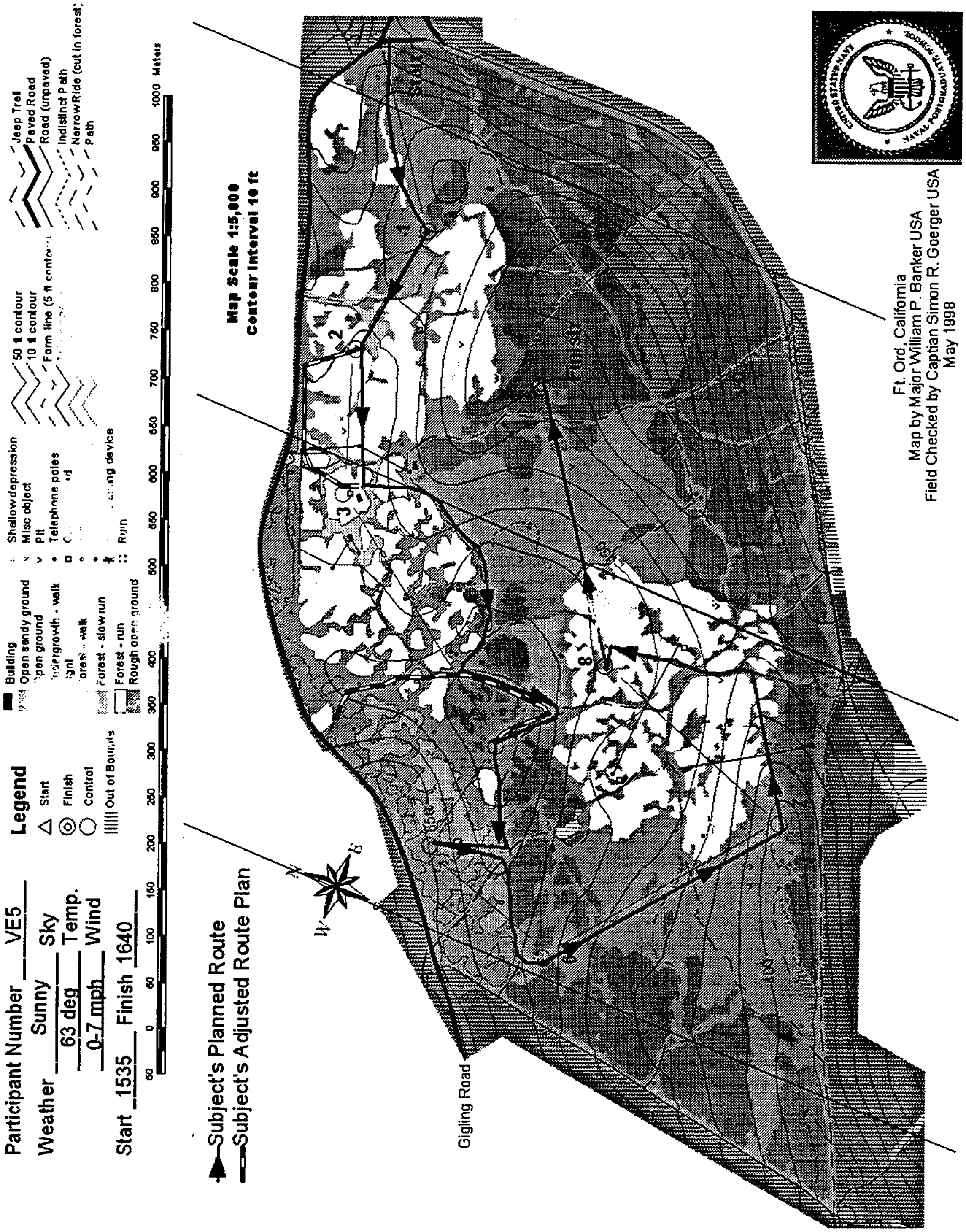


Figure N.77. VE5 Planned Route

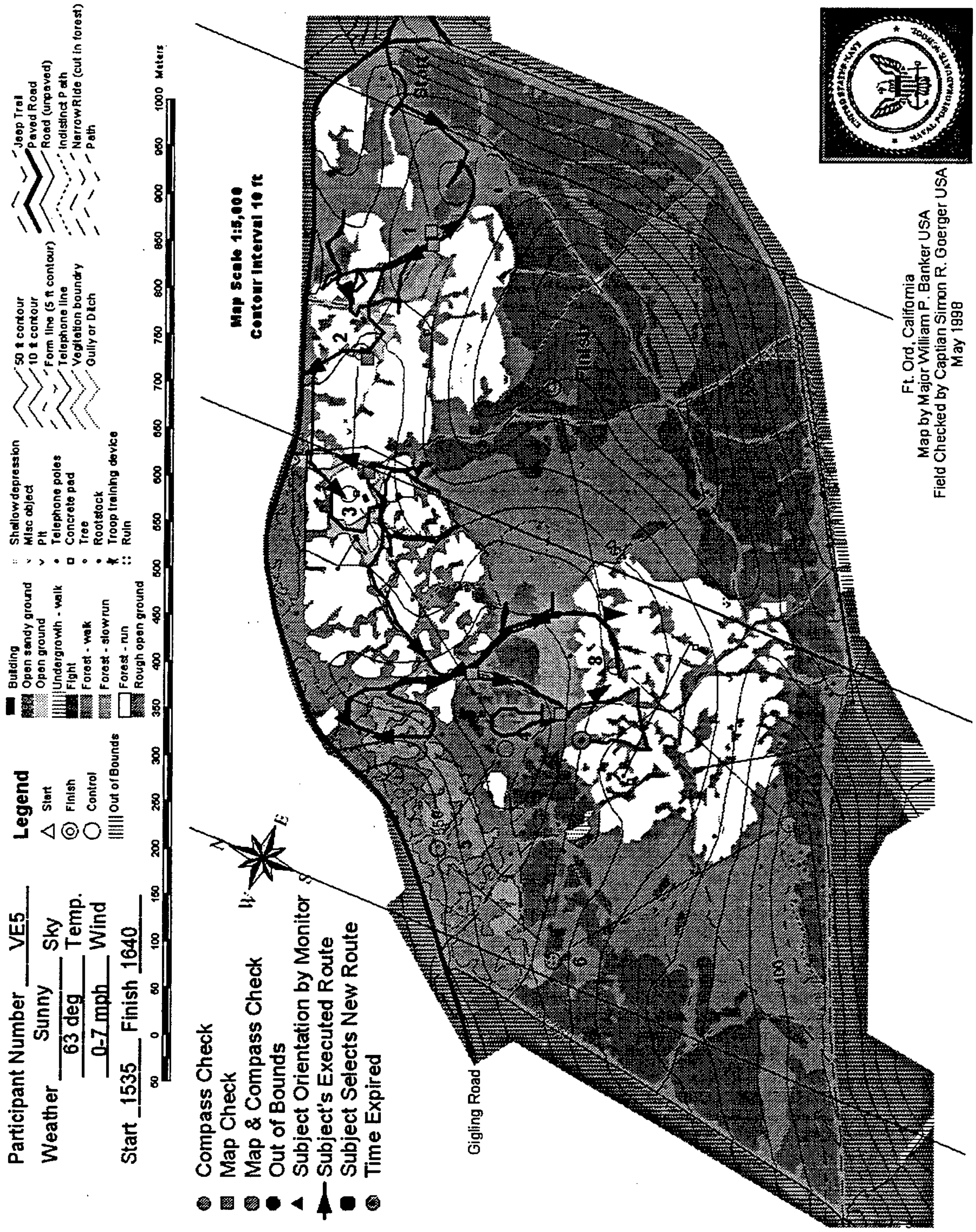


Figure N.78. VE5 Executed Route

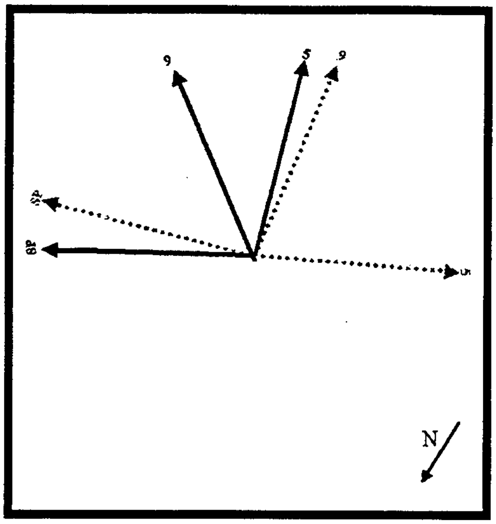


Figure N.79. VE5 Wheel Test CP # 2

SUBJECT DID NOT
REACH CP #4;
NO DATA
COLLECTED

Figure N.80. VE5 Wheel Test CP # 4

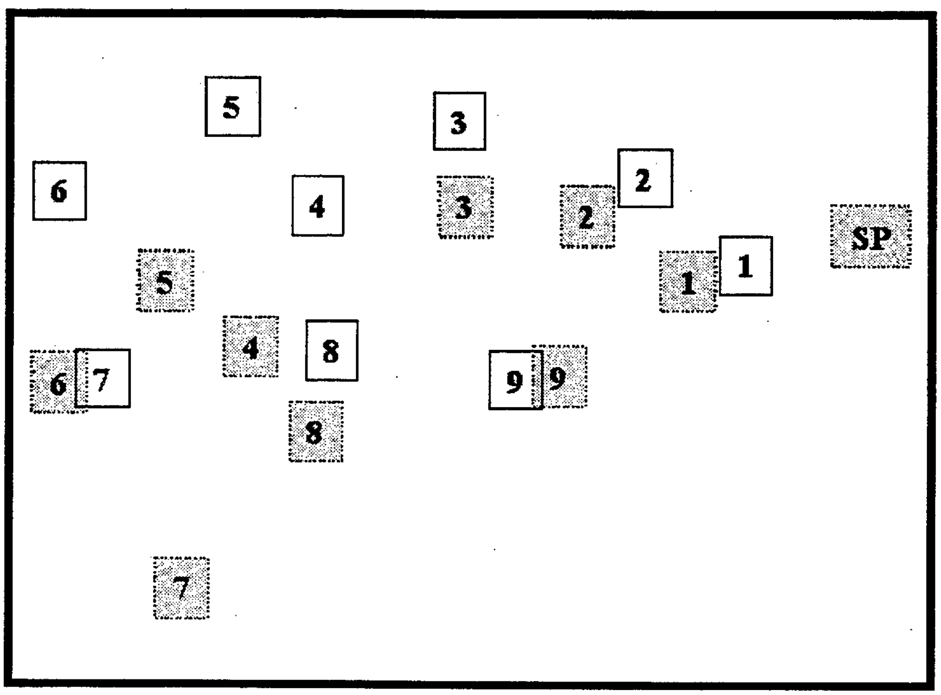


Figure N.81. VE5 White Board Test

APPENDIX O. RAW DATA

1. GENERAL INFORMATION

Participant data is referenced by the participant identification (ID) label (A – Assistant, M – Map, P – Pilot, RW – Real World, VE – Virtual Environment). The number corresponds to the participants internal group label. Data fields that are left blank represent information not recorded because a participant did not undergo the test or failed to reach that point in the course. Pilot participant data and assistant data is utilized for questionnaires only. The course data varied due to changes in experiment methodology for some of the pilot participants. Empty data fields represent information not recorded because the participant failed to undergo that portion of the experiment or did not wish to answer the question.

Participant ID	*Group*	*Age*	*Sex*	*Rank*	*Service*	*Branch*	*Self Assessed Ability*	*Test Date*	*Test Time*
M1	Map	29	M	O3	Army	EN	Intermediate	17-May	8:00
M2	Map	30	M	O3	Army	AR/CAV	Expert	1-Jun	15:00
M3	Map	33	M	O3	Marine	AV	Intermediate	5-Jun	7:30
M4	Map	30	M	O3	Marine	FA/MI	Intermediate	22-Jun	12:00
M5	Map	39	M	O5	Navy	AV	Intermediate	21-Jul	6:30
RW1	Real World	34	M	O4	Army	SC	Intermediate	29-May	13:00
RW2	Real World	29	M	O3	Navy	SEAL	Intermediate	14-Jun	13:00
RW3	Real World	37	M	O4	Marine	AV	Intermediate	16-Jun	13:00
RW4	Real World	30	M	O3	Marine	AV	Intermediate	10-Jul	7:00
RW5	Real World	34	M	O3	Army	AV	Intermediate	18-Jul	8:00
VE1	Virtual Env	30	M	O3	Army	AR/CAV	Expert	16-May	8:00
VE2	Virtual Env	28	M	O3	Marine	IN	Intermediate	20-May	8:00
VE3	Virtual Env	34	M	NA	Civilian	CIV	Intermediate	1-Jun	12:30
VE4	Virtual Env	29	F	O3	Marine	MI	Beginner	3-Jun	12:30
VE5	Virtual Env	35	M	O4	Army	AV	Beginner	10-Jul	13:00
A1	Pilot Grp 1	21	M	CDT	Air Force	Cadet	Beginner	18-May	17:00
P1	Pilot Grp 1	38	M	O4	Marine	FA/MI	Expert	15-May	8:00
P2	Pilot Grp 1	34	M	O4	Marine	IN	Expert	15-May	13:00
P3	Pilot Grp 1	28	M	O3	Marine	IT	Expert	16-May	13:00
P4	Pilot Grp 1	39	M	O4	Marine	UNK	Intermediate	17-May	13:00

2. INITIAL TESTES AND QUESTIONNAIRE RESULTS

The initial tests and questionnaires are in Appendix E. Answers for the Map Test are located in Appendix E.1.

Participant ID	*Map Test Score*	*Bar Evaluation*	*Santa Barbara (Raw Score)*	*Santa Barbara (Normalized)*	*Santa Barbara (Group)*	*GZ Score*	*GZ Ability Group*	*Banker Ability Group*
M1	19	Intermediate	42	2.80	High	48.75	High	Beginner
M2	17	Expert	46	3.07	High	22	High	Intermediate
M3	17	Intermediate	35	2.33	High	37	High	Intermediate
M4	20	Intermediate	31	2.07	High	12.25	Low	Intermediate
M5	16	Intermediate	36	2.40	High	16.25	Low	Beginner
RW1	16	Intermediate	40	2.67	High	10.25	Low	Beginner
RW2	19	Intermediate	34	2.27	High	11.5	Low	Intermediate
RW3	18	Intermediate	35	2.33	High	28.5	High	Intermediate
RW4	19	Intermediate	62	4.13	Low	18.5	Low	Beginner
RW5	19.5	Expert	35	2.33	High	21.25	High	Intermediate
VE1	18.5	Expert	31	2.07	High	8.25	Low	Intermediate
VE2	19.5	Intermediate	39	2.60	High	12.75	Low	Intermediate
VE3	15	Intermediate	30	2.00	High	22.25	High	Intermediate
VE4	17	Beginner	45	3.00	High	31.25	High	Beginner
VE5	13	Beginner	49	3.27	Low	8.75	Low	Beginner
A1	14.5	Beginner	47	3.13	High	26.75	High	Beginner
P1	19.5					1.75	Low	
P2	17					19.25	Low	
P3	17.5					24	High	
P4	18					24.75	High	

3. ROUTE ERRORS

The data provided in this section consists of the map checks, errors, error distances, and route leg classifications. The data appears in its raw form, summations, and normalized form for each of the experiments fifteen participants. The codes for the utilized are listed in Table O.1 and in the List of Abbreviations (pp _______).

Abbreviation	*Category*
C - #	Compass Check – Leg Number
M - #	Map Check – Leg Number
MC - #	Map and Compass Check – Leg Number
MCL - #	Map and Compass Check, Location Provided by Monitor – Leg Number
OB - #	Out of Bounds – Leg Number
New Rt - #	New Route Planned – Leg Number

Table O.1. Route Errors Abbreviation Table

a. Route Data Summation

Participant ID	*Controls Attempted*	*Control Found*	*Landmark Score*	*(Banker) Average Planned Route Difficulty Level*	*(Lisp) Average Planned Route Difficulty Level*
M1	9	9	9.00	1.56	1.67
M2	9	9	9.00	1.56	1.56
M3	9	9	9.00	1.78	1.89
M4	7	6	6.33	2.33	2.22
M5	4	3	3.66	1.44	1.67
RW1	6	5	5.33	2.67	2.67
RW2	8	8	8.00	2.44	2.44
RW3	9	9	9.00	1.44	1.56
RW4	4	3	3.33	2.67	2.56
RW5	9	9	9.00	1.11	1.00
VE1	9	9	9.00	1.67	1.67
VE2	4	3	3.33	1.44	1.44
VE3	7	7	7.00	1.56	1.78
VE4	7	6	6.33	1.22	1.11
VE5	4	3	3.33	2.00	2.22

Participant ID	*Errors-Tot*	*Errors Per CP Attempt*	*Dist-Tot*	*Dist Per Error*	*Normalized Error Score/Attempt*	*Normalized Error Score/Found (All)*	*Normalized Error Score/Found (Only)*
M1	5	0.56	3260	652	72.44	72.44	72.44
M2	5	0.56	937	187.4	20.82	20.82	20.82
M3	5	0.56	638	127.6	14.18	14.18	14.18
M4	5	0.71	3690	738	105.43	123	128.46
M5	4	1.00	3237	809.25	202.31	269.75	213.56
RW1	4	0.67	4017	1004.25	167.38	200.85	240.73
RW2	5	0.63	2136	427.2	53.4	53.4	53.4
RW3	3	0.33	448	149.33	16.59	16.59	16.59
RW4	7	1.75	4053	579	144.75	193	164.47
RW5	5	0.56	815	163	18.11	18.11	18.11
VE1	5	0.56	1270	254	28.22	28.22	28.22
VE2	5	1.25	6488	1297.6	324.4	432.53	442.22
VE3	7	1.00	3930	561.43	80.2	80.2	80.2
VE4	6	0.86	1593	265.5	37.93	44.25	47.1
VE5	6	1.50	4540	756.67	189.17	252.22	157.89

Participant ID	*Total Map Check Score*	*Normalized Map Check Score (Attempted)*	*Normalized Map Check Score (Found -All)*	*Normalized Map Check Score (Found-Only)*	*Controls Attempted*	*Controls Found*	*Landmark Score*
M1	10.5	1.17	1.17	1.17	9	9	9.00
M2	1.5	0.17	0.17	0.17	9	9	9.00
M3	13	1.44	1.44	1.44	9	9	9.00
M4	8.5	1.21	1.42	1.42	7	6	6.33
M5	12.50	3.13	4.17	3	4	3	3.66
RW1	34	5.67	6.8	6.3	6	5	5.33
RW2	23.5	2.94	2.94	2.94	8	8	8.00
RW3	0	0	0	0	9	9	9.00
RW4	16.5	4.13	5.5	4.33	4	3	3.33
RW5	13	1.44	1.44	1.44	9	9	9.00
VE1	0	0	0	0	9	9	9.00
VE2	31.5	7.88	10.5	6.33	4	3	3.33
VE3	22	3.14	3.14	3.14	7	7	7.00
VE4	14	2	2.33	2.17	7	6	6.33
VE5	10	2.5	3.33	1.5	4	3	3.33

b. Route Data Leg SP to CP1

Participant ID	*Errors SP-1*	*Total Dist-1*	*C-1*	*M-1*	*MC-1*	*MCL-1*	*OB-1*	*New Rt-1*	*Checks Score SP-1*	*Control Found SP-1*
M1	0	0	0	0	0	0	0	0	0	1
M2	0	0	0	0	0	0	0	0	0	1
M3	1	168	0	0	0	0	0	0	0	1
M4	0	0	0	0	0	0	0	0	0	1
M5	1	1400	0	1	0	0	0	0	1	1
RW1	0	0	0	0	0	0	0	0	0	1
RW2	0	0	0	0	0	0	0	0	0	1
RW3	0	0	0	0	0	0	0	0	0	1
RW4	1	211	0	0	0	0	0	0	0	1
RW5	0	0	0	0	0	0	0	0	0	1
VE1	1	150	0	0	0	0	0	0	0	1
VE2	2	3780	0	0	3	1	4	1	16	1
VE3	1	230	0	0	0	0	0	0	0	1
VE4	0	0	0	0	0	0	0	0	0	1
VE5	1	263	0	0	0	0	0	0	0	1

c. Route Data Leg CP1 to CP2

Participant ID	*Errors 1-2*	*Total Dist-2*	*C-2*	*M-2*	*MC-2*	*MCL-2*	*OB-2*	*New Rt-2*	*Checks Score 1-2*	*Control Found 1-2*
M1	0	0	0	0	0	0	0	0	0.00	1
M2	0	0	0	0	0	0	0	0	0.00	1
M3	1	216	0	0	0	0	0	0	0.00	1
M4	1	176	0	0	0	0	0	0	0.00	1
M5	1	150	0	1	0	0	0	0	1.00	1
RW1	1	1233	0	1	2	0	0	0	4.00	1
RW2	0	0	0	0	0	0	0	0	0.00	1
RW3	1	133	0	0	0	0	0	0	0.00	1
RW4	3	2129	0	2	2	1	0	1	8.50	1
RW5	1	220	0	1	0	0	0	0	1.00	1
VE1	0	0	0	0	0	0	0	0	0.00	1
VE2	0	0	0	0	0	0	0	0	0.00	1
VE3	0	0	0	0	0	0	0	0	0.00	1
VE4	0	0	0	0	0	0	0	0	0.00	1
VE5	1	548	0	0	0	0	0	0	0.00	1

d. Route Data Leg CP2 to CP3

Participant ID	*Errors 2-3*	*Total Dist-3*	*C-3*	*M-3*	*MC-3*	*MCL-3*	*OB-3*	*New Rt-3*	*Checks Score 2-3*	*Control Found 2-3*
M1	1	110	0	0	0	0	0	0	0.00	1
M2	1	190	0	0	0	0	0	0	0.00	1
M3	0	0	0	0	0	0	0	0	0.00	1
M4	2	2077	0	1	0	1	0	1	4.50	1
M5	1	372	0	2	0	0	1	0	4.00	1
RW1	0	0	0	0	0	0	0	0	0.00	1
RW2	0	0	0	0	0	0	0	0	0.00	1
RW3	0	0	0	0	0	0	0	0	0.00	1
RW4	1	127	0	0	0	0	0	0	0.00	1
RW5	1	227	0	1	0	0	0	0	1.00	1
VE1	1	160	0	0	0	0	0	0	0.00	1
VE2	1	200	0	0	0	0	0	0	0.00	1
VE3	1	216	0	1	0	0	0	0	1.00	1
VE4	1	180	0	0	0	0	0	0	0.00	1
VE5	1	610	0	0	0	0	0	0	0.00	1

e. Route Data Leg CP3 to CP4

Participant ID	*Errors 3-4*	*Total Dist-4*	*C-4*	*M-4*	*MC-4*	*MCL-4*	*OB-4*	*New Rt-4*	*Checks Score 3-4*	*Control Found 3-4*
M1	3	3050	0	4	0	1	0	3	8.5	1
M2	1	571	0	0	1	0	0	0	1.5	1
M3	1	40	0	0	0	0	0	0	0	1
M4	0	0	0	0	0	0	0	0	0	1
M5	1	1315	0	3	0	0	0	1	3.50	1
RW1	2	2378	0	3	6	1	0	1	15.5	1
RW2	2	1174	0	2	0	1	0	1	5.5	1
RW3	2	315	0	0	0	0	0	0	0	1
RW4	2	1586	0	2	1	0	0	0	3.5	0
RW5	0	0	0	0	0	0	0	0	0	1
VE1	1	480	0	0	0	0	0	0	0	1
VE2	2	2508	0	6	2	1	0	1	12.5	0
VE3	4	3386	1	10	1	1	0	3	17	1
VE4	2	1123	0	2	0	1	0	1	5.5	1
VE5	3	3119	0	2	0	1	0	1	5.5	0

f. Route Data Leg CP4 to CP5

Participant ID	*Errors 4-5*	*Total Dist-5*	*C-5*	*M-5*	*MC-5*	*MCL-5*	*OB-5*	*New Rt-5*	*Checks Score 4-5*	*Control Found 4-5*
M1	0	0	0	0	0	0	0	0	0	1
M2	1	110	0	0	0	0	0	0	0	1
M3	0	0	0	0	0	0	0	0	0	1
M4	0	0	0	0	0	0	0	0	0	1
M5										
RW1	0	0	0	0	0	0	0	0	0	1
RW2	1	275	0	1	0	0	0	0	1	1
RW3	0	0	0	0	0	0	0	0	0	1
RW4										
RW5	0	0	0	0	0	0	0	0	0	1
VE1	0	0	0	0	0	0	0	0	0	1
VE2										
VE3	1	98	0	0	0	0	0	0	0	1
VE4	1	50	0	0	0	0	0	0	0	1
VE5										

g. Route Data Leg CP5 to CP6

Participant ID	*Errors 5-6*	*Total Dist-6*	*C-6*	*M-6*	*MC-6*	*MCL-6*	*OB-6*	*New Rt-6*	*Checks Score 5-6*	*Control Found 5-6*
M1	0	0	0	0	0	0	0	0	0	1
M2	0	0	0	0	0	0	0	0	0	1
M3	1	54	0	0	0	0	0	0	0	1
M4	0	0	0	0	0	0	0	0	0	1
M5										
RW1	1	406	0	1	1	0	0	0	2.5	0
RW2	1	184	0	0	0	0	0	0	0	1
RW3	0	0	0	0	0	0	0	0	0	1
RW4										
RW5	0	0	0	0	0	0	0	0	0	1
VE1	0	0	0	0	0	0	0	0	0	1
VE2										
VE3	0	0	0	0	0	0	0	0	0	1
VE4	1	60	0	0	0	0	0	0	0	1
VE5										

h. Route Data Leg CP6 to CP7

Participant ID	*Errors 6-7*	*Total Dist-7*	*C-7*	*M-7*	*MC-7*	*MCL-7*	*OB-7*	*New Rt-7*	*Checks Score 6-7*	*Control Found 6-7*
M1	0	0	0	0	0	0	0	0	0	1
M2	0	0	0	0	0	0	0	0	0	1
M3	1	160	0	1	0	0	0	0	1	1
M4	1	607	0	2	0	0	1	0	4	0
M5										
RW1										
RW2	0	0	0	0	0	0	0	0	0	1
RW3	0	0	0	0	0	0	0	0	0	1
RW4										
RW5	1	78	0	0	0	0	0	0	0	1
VE1	0	0	0	0	0	0	0	0	0	1
VE2										
VE3	0	0	0	0	0	0	0	0	0	1
VE4	1	180	0	1	0	0	0	0	1	0
VE5										

i. Route Data Leg CP7 to CP8

Participant ID	*Errors 7-8*	*Total Dist-8*	*C-8*	*M-8*	*MC-8*	*MCL-8*	*OB-8*	*New Rt-8*	*Checks Score 7-8*	*Control Found 7-8*
M1	1	100	0	0	0	0	0	0	0	1
M2	0	0	0	0	0	0	0	0	0	1
M3	0	0	0	0	0	0	0	0	0	1
M4										
M5										
RW1	0	0	0	0	0	0	0	0	0	0
RW2	1	503	0	5	0	0	0	0	5	1
RW3	0	0	0	0	0	0	0	0	0	1
RW4										
RW5	1	105	0	0	0	0	0	0	0	1
VE1	0	0	0	0	0	0	0	0	0	1
VE2										
VE3										
VE4										
VE5										

j. Route Data Leg CP8 to CP9

Participant ID	*Errors 8-9*	*Total Dist-9*	*C-9*	*M-9*	*MC-9*	*MCL-9*	*OB-9*	*New Rt-9*	*Checks Score 8-9*	*Control Found 8-9*
M1	0	0	0	0	0	0	0	0	0	1
M2	2	66	0	0	0	0	0	0	0	1
M3	0	0	0	0	0	0	0	0	0	1
M4										
M5										
RW1										
RW2										
RW3	0	0	0	0	0	0	0	0	0	1
RW4										
RW5	1	185	0	0	0	0	0	0	0	1
VE1	2	480	0	0	0	0	0	0	0	1
VE2										
VE3										
VE4										
VE5										

k. Route Data Non Error Checks

Participant ID	*C-Non Errors*	*M-Non Errors*	*MC-Non Errors*	*MCL-Non Errors*	*OB-Non Errors*	*New Rt-Non Errors*	*Checks Score - Non Errors*
M1	0	2	0	0	0	0	2
M2	0	0	0	0	0	0	0
M3	0	11	0	0	0	2	12
M4	0	0	0	0	0	0	0
M5	0	0	0	0	0	0	0
RW1	0	0	8	0	0	0	12
RW2	3	0	6	0	0	0	12
RW3	0	0	0	0	0	0	0
RW4	0	0	3	0	0	0	4.5
RW5	0	8	0	0	0	4	10
VE1	0	0	0	0	0	0	0
VE2	0	2	1	0	0	0	3.5
VE3	0	2	0	0	0	1	2.5
VE4	0	6	0	0	0	1	6.5
VE5	0	4	0	0	0	0	4

l. Route Data Totals

Participant ID	*Errors-Tot*	*Distance -Tot*	*Distance Per Error*	*C-Tot*	*M-Tot*	*MC-Tot*	*MCL-Tot*	*OB-Tot*	*New Rt -Tot*
M1	5	3260	652	0	6	0	1	0	3
M2	5	937	187.4	0	0	1	0	0	0
M3	5	638	127.6	0	12	0	0	0	2
M4	5	3690	738	0	3	0	1	1	1
M5	4	3237	809.25	0	10	0	0	1	1
RW1	4	4017	1004.25	0	5	17	1	0	1
RW2	5	2136	427.2	3	8	6	1	0	1
RW3	3	448	149.33	0	0	0	0	0	0
RW4	7	4053	579	0	4	6	1	0	1
RW5	5	815	163	0	11	0	0	0	4
VE1	5	1270	254	0	0	0	0	0	0
VE2	5	6488	1297.6	0	8	6	2	4	1
VE3	7	3930	561.43	1	13	2	1	0	4
VE4	6	1593	265.5	0	10	0	1	0	2
VE5	6	4540	756.67	0	6	0	1	0	2

m. Leg Difficulty Evaluation Banker

Each leg is evaluated utilizing MAJ Banker's Route Classification (Appendix L.2). "B" stands for Beginner, "I" stands or Intermediate, and "A" stands for Advanced. The total is based on a point value system of B = 1, I = 2, and A = 3. The Average is the total divided by the number of legs. 0-1.50 is an average course difficulty of Beginner, 1.51-2.5 is Intermediate, and 2.51-3.0 is Advanced.

Participant ID	*Leg 1*	*Leg 2*	*Leg 3*	*Leg 4*	*Leg 5*	*Leg 6*	*Leg 7*	*Leg 8*	*Leg 9*	*Total*	*Average*
M1	B	I	I	I	I	B	I	B	B	14	1.56
[illegible]	B	I	I	I	B	B	I	I	B	14	1.56
[illegible]	I	I	I	I	I	B	I	B	I	16	1.78
[illegible]	I	I	I	A	I	B	A	A	A	21	2.33
M5	B	I	I	B	I	B	I	B	B	13	1.4
RW1	I	A	I	A	I	A	A	A	A	24	2.67
RW2	I	B	I	A	I	A	A	A	A	22	2.44
RW3	B	I	I	B	I	B	I	B	B	13	1.44
RW4	A	I	I	A	I	A	A	A	A	24	2.67
RW5	B	B	I	B	B	B	B	B	B	10	1.11
VE1	B	B	I	B	B	B	A	A	I	15	1.67
VE2	B	I	I	B	B	B	B	B	A	13	1.44
VE3	B	B	I	B	B	A	B	B	A	14	1.56
VE4	B	I	B	B	B	B	I	B	B	11	1.22
VE5	A	A	B	I	B	B	A	I	A	18	2.00

n. Leg Difficulty Evaluation LISP

Each leg is evaluated utilizing LISP Programs Route Classification (Appendix L.3). See above for code definitions and summation specifics.

Participant ID	*Leg 1*	*Leg 2*	*Leg 3*	*Leg 4*	*Leg 5*	*Leg 6*	*Leg 7*	*Leg 8*	*Leg 9*	*Total*	*Average*
M1	B	B	I	I	I	I	I	I	B	15	1.67
M2	B	B	I	I	B	I	I	I	B	14	1.56
M3	I	B	I	I	I	I	I	I	I	17	1.89
M4	I	B	I	A	I	B	A	A	A	20	2.22
M5	B	B	I	B	I	B	I	I	B	15	1.7
RW1	I	A	I	A	I	A	A	A	A	24	2.67
RW2	I	B	I	A	I	A	A	A	A	22	2.44
RW3	B	B	I	B	I	I	I	I	B	14	1.56
RW4	A	B	I	A	I	A	A	A	A	23	2.56
RW5	B	B	B	B	B	B	B	B	B	9	1.00
VE1	B	B	I	B	B	I	I	A	I	15	1.67
VE2	B	B	I	B	B	I	B	B	A	13	1.44
VE3	B	I	I	B	B	A	B	I	A	16	1.78
VE4	B	B	B	B	B	I	B	B	B	10	1.11
VE5	A	A	B	I	B	I	A	I	A	20	2.22

4. WHEEL TEST RESULTS

a. Wheel Test Results for Control Point 2

Participant ID	*Orient*	*Time (sec)*	*SP*	*CP5*	*CP9*	*Dif CP1*	*Dif CP6*	*Dif CP8*	*Ave Angular Diff CP2*
M1	North	47	124	271	164	-54	-31	6	30.33
M2	South	12	78	229	166	-8	11	4	7.67
M3	North	16	77	248	147	-7	-8	23	12.67
M4	West	43	41	183	120	29	57	50	45.33
M5	South	40	118	201	145	-48	39	25	37.33
RW1	South	58	76	204	113	-6	36	57	33.00
RW2	South	17	85	240	141	-15	0	29	14.67
RW3	South	27	65	206	167	5	34	3	14.00
RW4	West	29	52	163	88	18	77	82	59.00
RW5	North	15	68	243	122	2	-3	48	17.67
VE1	Arrows	48	83	249	166	-13	-9	4	8.67
VE2	South	53	86	237	129	-16	3	41	20.00
VE3	South	15	87	242	141	-17	-2	29	16.00
VE4	South	40	74	218	164	-4	22	6	10.67
VE5	SE	22	59	161	124	11	79	46	45.33

b. Wheel Test Results for Control Point 4 and Total Wheel Test Angular Difference

Total Wheel Test Angular Difference is the value of the Average Angular Differences for CP2 and CP4 divided by two. No data was collected on four individuals (M5, RW4, VE2, and VE5) because they failed to reach Control Point 4. Their Total Wheel Test Angular Difference is the save as the value for the Average Angular Differences for CP2.

Participant ID	*Orient*	*Time (sec)*	*CP1*	*CP6*	*CP8*	*Diff CP1*	*Diff CP6*	*Diff CP8*	*Ave Angular Diff CP4*	*Total Wheel Test Angular Diff*
M1	South	38	86	227	153	-28	8	-37	24.33	27.33
M2	South	16	59	234	185	-1	1	-69	23.67	15.67
M3	North	18	69	252	168	-11	-17	-52	26.67	19.67
M4	South	47	49	187	110	9	48	6	21.00	33.17
M5										37.33
RW1	South	28	74	230	182	-16	5	-66	29.00	31.00
RW2	South	24	57	240	180	1	-5	-64	23.33	19.00
RW3	South	27	91	247	114	-33	-12	2	15.67	14.83
RW4										59.00
RW5	East	29	53	221	126	5	14	-10	9.67	13.67
VE1	Arrows	62	30	168	110	28	67	6	33.67	21.17
VE2										20.00
VE3	East	17	71	226	151	-13	9	-35	19.00	17.50
VE4	East/N	60	89	269	180	-31	-34	-64	43.00	26.83
VE5										45.33

5. WHITE BOARD RESULTS

a. White Board Normalized Distance Differences from Actual Normalized Distances

ID	*SP to CP1*	*CP1 to CP2*	*CP2 to CP3*	*CP3 to CP4*	*CP4 to CP5*	*CP5 to CP6*	*CP6 to CP7*	*CP7 to CP8*	*CP8 to CP9*	*CP9 to SP*	*Total WB Norm Dist*	*Avg WB Norm Dist*
M1	-0.01	-0.01	-0.01	0.03	0.03	0.06	-0.04	-0.01	0.03	-0.08	0.33	0.033
M2	-0.01	0.00	-0.02	-0.04	0.06	0.01	-0.02	-0.01	0.04	0.00	0.23	0.023
M3	0.02	0.00	-0.01	-0.04	0.03	0.02	0.00	0.06	-0.06	-0.01	0.27	0.027
M4	0.00	0.03	-0.01	-0.03	0.02	0.09	-0.01	-0.05	-0.04	0.00	0.28	0.028
M5	0.02	0.00	-0.03	0.02	0.03	0.02	-0.01	0.01	-0.03	-0.03	0.19	0.019
RW1	0.00	0.03	0.00	-0.05	0.01	0.04	-0.02	0.03	-0.04	-0.01	0.22	0.022
RW2	-0.01	0.01	0.01	-0.03	0.05	0.03	-0.02	-0.01	0.00	-0.03	0.19	0.019
RW3	-0.03	-0.01	-0.01	0.00	0.02	0.04	0.02	0.04	-0.06	0.00	0.24	0.024
RW4	-0.01	0.01	0.01	-0.03	0.05	0.06	-0.04	-0.03	-0.04	0.02	0.30	0.030
RW5	-0.02	-0.04	0.01	0.00	0.01	0.08	-0.01	0.00	-0.03	0.00	0.20	0.020
VE1	-0.01	0.00	0.01	-0.03	0.03	0.02	0.02	0.03	-0.05	0.00	0.20	0.020
VE2	0.01	0.00	-0.01	-0.02	0.03	0.02	0.01	0.03	-0.02	-0.04	0.18	0.018
VE3	-0.01	0.00	0.00	0.00	0.03	0.03	0.03	0.01	-0.07	-0.03	0.22	0.022
VE4	-0.03	0.00	0.00	-0.03	0.03	0.04	0.07	-0.01	-0.04	-0.04	0.30	0.030
VE5	-0.02	0.01	0.03	-0.04	0.01	0.03	-0.02	0.01	-0.03	0.02	0.23	0.023

b. White Board Angles

ID	*SP,1,2*	*1,2,3*	*2,3,4*	*3,4,5*	*4,5,6*	*5,6,7*	*6,7,8*	*7,8,9*	*8,9,SP*	*9,SP,1*
M1	161.23	130.76	162.90	96.53	47.81	112.71	112.29	169.01	177.02	37.31
M2	133.81	131.06	173.55	137.39	101.58	110.53	92.07	141.61	121.66	29.47
M3	125.11	141.25	130.59	96.82	96.61	109.81	90.87	169.30	166.80	15.28
M4	85.52	114.74	158.31	104.45	62.82	86.72	165.41	119.66	149.12	8.58
M5	123.36	165.73	169.87	144.34	89.52	88.99	162.31	173.04	126.86	82.20
RW1	165.20	151.99	138.50	90.27	86.18	100.58	97.92	145.11	151.48	33.95
RW2	178.66	178.82	122.12	111.69	90.88	99.38	120.00	149.72	140.01	48.87
RW3	179.06	120.49	116.90	105.25	70.42	102.98	89.88	84.67	80.07	31.09
RW4	173.85	126.46	157.38	144.36	98.15	76.53	157.19	138.46	136.72	64.26
RW5	125.65	139.22	166.89	83.93	55.93	82.50	113.71	145.63	127.68	29.28
VE1	137.66	145.01	158.50	120.34	82.54	125.84	78.04	144.58	152.02	20.63
VE2	166.37	150.42	123.21	86.74	114.92	92.34	96.62	179.27	174.90	39.97
VE3	119.82	144.85	131.46	69.32	59.17	99.73	97.81	148.98	142.00	23.10
VE4	178.52	145.75	157.28	116.17	89.60	90.86	91.11	112.73	120.89	74.89
VE5	119.67	144.39	144.32	106.83	103.46	104.45	96.59	160.99	145.83	8.46

c. White Board Angles Differences from Actual Angles and Totals

ID	*SP,1,2*	*1,2,3*	*2,3,4*	*3,4,5*	*4,5,6*	*5,6,7*	*6,7,8*	*7,8,9*	*8,9,SP*	*9,SP,1*	*Total WB Angle Diff*	*Avg WB Angle Diff*
M1	27.64	8.09	-7.91	-31.71	-50.78	6.29	39.74	22.39	9.04	26.26	229.87	22.987
M2	0.23	8.39	2.74	9.15	2.99	4.11	19.52	-5.01	-46.32	18.42	116.87	11.687
M3	-8.48	18.58	-40.22	-31.42	-1.98	3.39	18.32	22.68	-1.17	4.24	150.47	15.047
M4	-48.07	-7.93	-12.50	-23.79	-35.77	-19.69	92.86	-26.96	-18.86	-2.47	288.88	28.888
M5	-10.22	43.07	-0.94	16.10	-9.08	-17.43	89.75	26.42	-41.11	71.16	325.27	32.527
RW1	31.62	29.32	-32.32	-37.97	-12.41	-5.84	25.37	-1.51	-16.49	22.90	215.74	21.574
RW2	45.07	56.15	-48.70	-16.55	-7.72	-7.04	47.45	3.10	-27.97	37.82	297.57	29.757
RW3	45.48	-2.18	-53.91	-22.99	-28.17	-3.44	17.33	-61.95	-87.90	20.04	343.39	34.339
RW4	40.27	3.79	-13.43	16.13	-0.45	-29.89	84.64	-8.16	-31.25	53.21	281.21	28.121
RW5	-7.94	16.55	-3.92	-44.31	-42.66	-23.92	41.16	-0.99	-40.30	18.23	239.97	23.997
VE1	4.07	22.34	-12.31	-7.90	-16.05	19.42	5.49	-2.04	-15.96	9.58	115.15	11.515
VE2	32.78	27.75	-47.60	-41.50	16.33	-14.08	24.07	32.65	6.92	28.93	272.62	27.262
VE3	-13.77	22.18	-39.35	-58.91	-39.42	-6.69	25.25	2.36	-25.98	12.06	245.97	24.597
VE4	44.94	23.08	-13.53	-12.07	-8.99	-15.56	18.55	-33.89	-47.08	63.84	281.54	28.154
VE5	-13.91	21.72	-26.49	-21.41	4.87	-1.97	24.04	14.37	-22.15	-2.59	153.51	15.351

6. UNPLANNED ROUTE RESULTS

Participant ID	*Direction from CP9 to CP4*	*Distance to CP4*	*Route*	*Time (min)*	*Errors Unplanned Route*	*Distance Unplanned Route*
M1	West	200m	Trail S & E to CP8, W to CP4	6:17	0	0
M2	West	200m	Trail N to clearing, W to CP4	6:07	0	0
M3	WestSouthWest	350m	Trail toward CP8, trail toward CP6, & E to CP4	7:26	0	0
M4						
M5						
RW1						
RW2						
RW3	WestSouthWest	300m	Trail N to CP3, W to CP4	3:28	0	0
RW4						
RW5	WestNorthWest	250m	Trail N to CP3, W to CP4	4:53	0	0
VE1	West	400m	Trail N to CP3, W to CP4	4:39	0	0
VE2						
VE3						
VE4						
VE5						

7. DEBRIEFING QUESTIONNAIRE RESULTS

a. Map Questions

Participant ID	*Question 1*	*Question 2*	*Question 3*	*Question 4*	*Question 5*	*Question 6*	*Question 7*
M1	2	4	4	5	5	4	2
M2	3	4	4	5	3	4	2
M3	4	4	5	5	4	4	2
M4	4	5	5	5	5	5	1
M5	4	3	3	4	3	4	2
RW1	4	4	2	2	3	3	3
RW2	4	4	3	4	4	4	2
RW3	4	3	5	5	4	3	1
RW4	2	2	3	2	2	3	3
RW5	4	4	4	5	4	3	2
VE1	5	5	4	4	4	1	2
VE2	4	4	2	4	3	3	2
VE3	3	4	3	4	4	4	1
VE4	4	4	4	5	3	2	2
VE5	4	3	4	4	3	4	2
A1	4	5	4	3	2	2	2
P1	5	4	3	4		3	1
P2	5	5	3	4	4	2	1
P3	3	5	2	4	4	2	2
P4	5	5					1

b. Course Questions

Participant ID	*Question 1*	*Question 2*	*Question 3*	*Question 4*	*Question 5*
M1	2	5	4	2	4
M2	2	4	4	4	2
M3	3	4	5	3	4
M4	4	5	5	4	4
M5	5	5	4	1	5
RW1	4	5	4	1	5
RW2	3	4	4	2	3
RW3	2	5	5	2	2
RW4	4	4	2	4	5
RW5	3	5	5	1	4
VE1	2	3	4	1	2
VE2	4	4	4	2	3
VE3	3	5	5	4	2
VE4	5	4	4	3	5
VE5	5	5	5	3	5
A1	3	5	5	3	3
P1	3	1	5	1	5
P2	3	5	2	3	2
P3	3	5	5	3	4
P4					

c. Miscellaneous Questions

Participant ID	*Question 1*	*Question 2*	*Question 3*	*Question 4*	*Question 5*
M1	5	5	2	3	5
M2	5	4	2	4	4
M3	5	5	1	4	4
M4	5	5	1	5	3
M5	5	5	1	4	3
RW1	4	3	3	4	1
RW2	4	4	2	4	1
RW3	5	5	1	5	4
RW4	5	2	5	5	2
RW5	5	3	3	4	4
VE1	5	5	1	5	5
VE2	5	2	4	2	3
VE3	5	5	1	4	4
VE4	5	4	2	2	1
VE5	5	2	4	3	2
A1	4	2	4	5	3
P1	5	4	2	3	2
P2	4	4	2	4	1
P3	5	2	4	4	2
P4	4	5	1		2

d. Model Questions

ID	*Quest 1*	*Quest 2*	*Quest 3*	*Quest 4*	*Quest 5*	*Quest 6*	*Quest 7*	*Quest 8*	*Quest 9*	*Quest 10*	*Quest 11*	*Quest 12*	*Quest 13*	*Quest 14*
M1														
M2														
M3														
M4														
M5														
RW1														
RW2														
RW3														
RW4														
RW5														
VE1	5	5	4	4	4	1	5	3	5	1	5	5	5	5
VE2	4	4	2	4	3	3	3	4	4	1	4	4	4	2
VE3	4	4	3	5	4	4	5	4	4	2	5	5	5	5
VE4	5	5	4	3	3	2	2	1	4	3	4	5	5	5
VE5	4	4	4	4	4	4	4	2	2	4	1	1	5	1
A1	3	4	2	5	3	3	4	4	5	2	5	5	5	5
P1	5	5	5	5	3	4	1	1	5	2	2	1	5	
P2	4	4	4	4	4	2	2	3	4	1	4	5	5	5
P3	4	4	4	4	3	1	3	4	4	4	4	4	4	4
P4	3	4								3	3	2	3	4

e. Interface Questions

Participant ID	*Question 1*	*Question 2*	*Question 3*	*Question 4*	*Question 5*	*Question 6*	*Question 7*	*Question 8*
M1								
M2								
M3								
M4								
M5								
RW1								
RW2								
RW3								
RW4								
RW5								
VE1	5	4	4	4	4	5	5	1
VE2	4	4	4	3	4	3	3	2
VE3	5	5	5	5	5	5	5	1
VE4	5	5	5	5	5	5	5	1
VE5	5	5	5	5	5	5	5	1
A1	4	5	4	5	4	5	5	1
P1	5	5	5	5	5	5	5	2
P2	5	5	4	4	4	5	4	2
P3	4	5	5	5	4	4	4	3
P4	4	4	4	4	4	5	5	

f. Descriptive Statistics for Debriefing Questionnaire

The following table displays summary of the descriptive statistics for the questionnaire minus the data for the pilot participants. The total number of participants is 15. Missing data is from questions that were not administered to real world and map group participants.

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
MapQ1	3.667	.816	.211	15	2.000	5.000	0
MapQ2	3.800	.775	.200	15	2.000	5.000	0
MapQ3	3.667	.976	.252	15	2.000	5.000	0
MapQ4	4.200	1.014	.262	15	2.000	5.000	0
MapQ5	3.600	.828	.214	15	2.000	5.000	0
MapQ6	3.400	.986	.254	15	1.000	5.000	0
MapQ7	1.933	.594	.153	15	1.000	3.000	0
CourseQ1	3.400	1.121	.289	15	2.000	5.000	0
CourseQ2	4.467	.640	.165	15	3.000	5.000	0
CourseQ3	4.267	.799	.206	15	2.000	5.000	0
CourseQ4	2.467	1.187	.307	15	1.000	4.000	0
CourseQ5	3.667	1.234	.319	15	2.000	5.000	0
MiscQ1	4.867	.352	.091	15	4.000	5.000	0
MiscQ2	3.933	1.223	.316	15	2.000	5.000	0
MiscQ3	2.200	1.320	.341	15	1.000	5.000	0
MiscQ4	3.867	.990	.256	15	2.000	5.000	0
MiscQ5	3.067	1.387	.358	15	1.000	5.000	0
Model Q1	4.400	.548	.245	5	4.000	5.000	10
ModelQ2	4.400	.548	.245	5	4.000	5.000	10
ModelQ3	3.400	.894	.400	5	2.000	4.000	10
ModelQ4	4.000	.707	.316	5	3.000	5.000	10
ModelQ5	3.600	.548	.245	5	3.000	4.000	10
ModelQ6	2.800	1.304	.583	5	1.000	4.000	10
ModelQ7	3.800	1.304	.583	5	2.000	5.000	10
ModelQ8	2.800	1.304	.583	5	1.000	4.000	10
ModelQ9	3.800	1.095	.490	5	2.000	5.000	10
ModelQ10	2.200	1.304	.583	5	1.000	4.000	10
ModelQ11	3.800	1.643	.735	5	1.000	5.000	10
ModelQ12	4.000	1.732	.775	5	1.000	5.000	10
ModelQ13	4.800	.447	.200	5	4.000	5.000	10
ModelQ14	3.600	1.949	.872	5	1.000	5.000	10
InterfaceQ1	4.800	.447	.200	5	4.000	5.000	10
InterfaceQ2	4.600	.548	.245	5	4.000	5.000	10
InterfaceQ3	4.600	.548	.245	5	4.000	5.000	10
InterfaceQ4	4.400	.894	.400	5	3.000	5.000	10
InterfaceQ5	4.600	.548	.245	5	4.000	5.000	10
InterfaceQ6	4.600	.894	.400	5	3.000	5.000	10
InterfaceQ7	4.600	.894	.400	5	3.000	5.000	10
InterfaceQ8	1.200	.447	.200	5	1.000	2.000	10

g. Model Needs

For the each item "1" means the items does need to be included and "0" means the items does not need to be included in a model used to prepare an individual to navigate through the actual terrain.

1) Buildings

Participant ID	*factory*	*houses*	*public buildings*	*shacks*
M1	1	1	1	1
M2	1	1	1	1
M3	1	1	1	1
M4	1	1	1	0
M5	1	1	1	1
RW1	1	1	1	1
RW2	1	1	1	1
RW3	1	1	1	1
RW4	1	1	1	1
RW5	1	1	1	1
VE1	1	1	1	1
VE2	1	1	1	1
VE3	1	0	1	0
VE4	1	1	1	0
VE5	1	1	1	1
A1	1	1	1	1
P1	1	1	1	1
P2	1	1	1	1
P3	1	1	1	1
P4	1	1	1	0

2) Miscellaneous Objects

Participant ID	*animals*	*compass*	*people*	*road signs*	*rock piles*	*sand bags*	*sound*	*street signs*	*the sun*
M1	0	1	0	0	0	0	1	0	0
M2	0	1	0	1	0	0	0	1	0
M3	0	1	0	0	0	0	1	1	1
M4	0	0	0	1	1	1	0	1	1
M5	0	1	0	1	0	0	0	1	0
RW1	0	1	0	1	0	1	0	0	0
RW2	0	1	0	0	0	0	0	0	0
RW3	0	0	0	0	1	0	0	0	0
RW4	0	1	0	0	0	0	0	0	0
RW5	0	1	0	0	0	0	0	1	1
VE1	0	1	0	0	1	0	1	0	1
VE2	0	1	0	0	0	0	0	0	0
VE3	0	0	0	0	0	0	0	0	0
VE4	0	0	0	0	0	0	0	0	0
VE5	0	1	0	0	1	0	0	0	1
A1	0	1	0	1	1	1	1	1	0
P1	0	0	0	1	0	0	0	1	1
P2	0	1	1	1	1	1	0	1	0
P3	0	1	0	1	0	0	1	1	1
P4	0	1	0	0	0	0	0	0	1

3) Obstacles

Participant ID	*electric lines*	*pits/fox holes*	*shallow ditches*	*telephone poles*	*towers*	*trenches*
M1	1	0	0	1	1	0
M2	1	1	1	1	1	1
M3	0	1	1	1	1	1
M4	1	1	1	1	1	1
M5	1	0	0	1	1	1
RW1	0	0	0	1	1	1
RW2	1	0	0	1	1	0
RW3	1	1	1	1	1	1
RW4	1	1	0	1	1	1
RW5	1	0	0	1	1	1
VE1	1	0	1	1	1	1
VE2	1	0	0	1	1	0
VE3	1	1	1	0	1	1
VE4	1	0	0	1	1	0
VE5	1	1	1	1	1	1

Participant ID	electric lines	pits/fox holes	shallow ditches	telephone poles	towers	trenches
A1	1	1	1	1	1	1
P1	1	0	0	1	1	0
P2	1	0	1	1	1	1
P3	1	1	1	1	1	1
P4	1	0	0	1	1	1

4) Roads

Participant ID	dirt roads	foot paths	paved roads	trails
M1	1	0	1	1
M2	1	0	1	1
M3	1	1	1	1
M4	1	1	1	1
M5	1	1	1	1
RW1	1	0	1	1
RW2	1	0	1	0
RW3	1	1	1	1
RW4	1	0	1	1
RW5	1	1	1	1
VE1	1	0	1	1
VE2	1	0	1	0
VE3	1	1	1	1
VE4	0	0	0	0
VE5	1	1	1	1
A1	1	1	1	1
P1	1	1	1	1
P2	1	1	1	1
P3	1	1	1	1
P4	1	0	1	1

5) Terrain

Participant ID	depressions	draws	hills	knolls	ridgelines	spurs/fingers
M1	1	0	1	1	1	1
M2	1	0	1	1	1	1
M3	1	0	1	1	1	1
M4	1	0	1	1	1	1
M5	1	1	1	1	1	1
RW1	1	0	1	0	1	1
RW2	0	0	1	1	1	1
RW3	1	0	1	1	1	1
RW4	1	0	1	1	1	1
RW5	1	0	1	1	1	1
VE1	1	1	1	1	1	1
VE2	1	0	1	0	1	1
VE3	1	0	1	1	1	1

Participant ID	*depressions*	*draws*	*hills*	*knolls*	*ridgelines*	*spurs/fingers*
VE4	1	0	1	0	1	1
VE5	1	0	1	1	1	1
A1	1	0	1	1	1	1
P1	1	0	1	1	1	1
P2	1	0	1	1	1	1
P3	1	0	1	1	1	1
P4	1	0	1	1	1	1

6) Vegetation

Participant ID	*bushes*	*clearings*	*flowers*	*grass/weeds*	*trees*	*undergrowth*
M1	1	1	0	0	1	0
M2	1	1	0	1	1	0
M3	1	1	0	0	1	0
M4	1	1	0	1	1	0
M5	0	1	0	0	1	0
RW1	1	1	0	1	1	0
RW2	0	1	0	0	1	0
RW3	0	1	0	1	1	0
RW4	1	1	0	0	0	0
RW5	1	1	0	1	1	0
VE1	1	1	0	0	1	0
VE2	0	1	0	0	1	0
VE3	0	1	0	0	0	0
VE4	0	1	0	0	0	0
VE5	1	1	0	1	1	0
A1	1	1	0	1	1	0
P1	1	1	0	1	1	1
P2	1	1	0	1	1	0
P3	1	1	0	1	1	0
P4	0	1	0	0	1	0

7) Miscellaneous Items

Participant ID	*lakes*	*marsh lands*	*ponds*	*puddles*	*stream/river*	*swamps*
M1	1	1	1	0	1	1
M2	1	1	1	0	1	1
M3	1	1	1	0	0	1
M4	1	1	1	0	0	1
M5	1	1	1	0	1	1
RW1	1	1	1	1	0	1
RW2	1	1	0	0	0	0
RW3	1	1	1	0	0	1
RW4	1	0	1	0	0	0
RW5	1	1	1	0	0	1
VE1	1	1	1	1	0	1
VE2	1	0	1	0	0	0

Participant ID	lakes	marsh lands	ponds	puddles	stream/river	swamps
VE3	1	1	1	0	0	1
VE4	1	1	0	0	0	1
VE5	1	1	1	1	0	1
A1	0	0	0	0	0	0
P1	1	0	1	0	1	1
P2	1	1	1	0	0	1
P3	1	1	1	0	1	1
P4	1	0	1	0	0	0

h. Top Six Model Needs

Participant ID	1	2	3	4	5	6
M1	Hills	Ridge Lines	Dirt Roads	Spurs	Rivers/Streams	Electric Lines
M2	Buildings	Trails	Electric Lines	Trees	Rivers/Streams	Elevation
M3	Hills	Spurs/Fingers	Trails	Clearings	Buildings	Compass
M4	Hills	Fingers	Ridge Lines	Depressions	Paved Roads	Dirt Roads
M5	Compass	Paved Roads	Dirt Roads	Hills	Clearings	Trails
RW1	Roads	Trees	Buildings	Elevation	Compass	Hills
RW2	Dirt Roads	Paved Roads	Clearings	Knolls	Spurs	Trees
RW3	Roads	Trails	Clearings	Trees	Hills	Telephone Poles
RW4	Buildings	Trails	Poles	Lakes	Hills	Depressions
RW5	Hills	Ridge Lines	Paved Roads	Lakes	Trees	Public Buildings
VE1	Hills	Spurs	Trails	Buildings	Ponds	Compass
VE2	Hills	Fingers	Compass	Buildings	Roads	Lakes
VE3	Roads	Paths	Electric Lines	Ridge Lines	Hills	Lakes
VE4	Paved Roads	Dirt Roads	Hills	Fingers	Telephone Poles	Buildings
VE5	Houses	Dirt Roads	Electric Lines	Hills	Lakes	Ponds
A1	Paved Roads	Dirt Roads	Ridge Lines	Lakes	Hills	Electric Lines
P1	Hills	Ridge Lines	Dirt Roads	Paved Roads	Spurs	Clearings/Trees
P2	Dirt Roads	Paved Roads	Buildings	Trails	Rivers/Streams	Hills
P3	Paved Roads	Dirt Roads	Public Buildings	Houses	Lakes	Trees
P4	Dirt Roads	Trails	Paved Roads	Shacks	Towers	Electric Lines

APPENDIX P. ENVIRONMENT COMPARISONS

1. GENERAL INFORMATION

This appendix outlines the differences in the training conditions and participant results between the Banker and Goerger experiments. The training conditions include a non-real time model, real time model, real world exposure, and map only study. *NA* indicates characteristics that do not apply to a training condition due to the nature of the training medium. Results are broken down by experiment and by training condition. Results such as the Total Map Check Scores, Wheel Test Angular Differences and White Board Angular Differences are not directly comparable because of the different information included, means of measurement, or tests conducted in the separate experiments.

2. ENVIRONMENT CHARACTERISTICS

The following is a listing of characteristics and which training treatment implements each one.

Characteristic	*Non-Real Time Model (Banker)*	*Real Time Model (Goerger)*	*Real World*	*Map*
"You are here!" Designator (Constant)	Yes	No	No	NA
"You are here!" Designator (On Demand)	Yes	Yes	No	NA
1.5m to 2m Elevated View Point	Yes	Yes	Yes	No
15m Elevated View Point	No	Yes	No	No
Animals	No	No	Yes	NA
Boundary Terrain	No	Yes	Yes	Yes
Bushes	Yes	Yes	Yes	NA
Clearings	Yes	Yes	Yes	Yes
Compass	No	Yes	Yes	NA
Continues Model	No	Yes	Yes	Yes
Depressions	Yes	Yes	Yes	Yes
Dirt Roads	Yes	Yes	Yes	Yes
Draws	Yes	Yes	Yes	Yes
Electric Lines	No	No	Yes	Yes
Factory	No	No	No	No
Flowers	No	No	Yes	No
Foot Paths	Yes	Yes	Yes	Yes
Grass/Weeds	Yes	No	Yes	No
Hills	Yes	Yes	Yes	Yes
Houses	No	No	No	No
Interface Testing	No	Yes	No	No
Interface Train-Up Phase	No	Yes	No	No
Joystick Interface	No	Yes	No	No
Keyboard Interface	Yes	Yes	No	No
Knolls	Yes	Yes	Yes	Yes
Lakes	No	No	No	No

Characteristics (continued)	*Non-Real Time Model (Banker)*	*Real Time Model (Goerger)*	*Real World*	*Map*
LOD Snapping/Popping	No	Yes	No	No
Marsh Lands	No	No	No	No
Mouse Interface	Yes	No	No	No
Paved Roads	Yes	Yes	Yes	Yes
Pedometer (Distance Traveled)	No	No	Yes	Yes
People	No	No	Yes	No
Pitch Viewpoint Up/Down	No	Yes	Yes	NA
Pits/Fox Holes	Yes	No	Yes	Yes
Ponds	No	No	Yes	No
Power Lines	No	No	Yes	Yes
Public Buildings	No	No	No	No
Puddles	No	No	No	No
Real Time	No	Yes	Yes	NA
Realistic Control Point Markers	No	Yes	Yes	Yes
Realistic Telephone Poles	No	Yes	Yes	Yes
Ridgelines	Yes	Yes	Yes	Yes
River	No	No	No	No
Road Signs	No	No	Yes	No
Rock Piles	Yes	Yes	Yes	Yes
Rotate view to side while moving	No	Yes	Yes	NA
Sand Bags	No	Yes	Yes	No
Shacks	Yes	Yes	Yes	Yes
Shadows	No	Yes	Yes	No
Shallow Ditches	Yes	Yes	Yes	Yes
Sound	No	No	Yes	No
Spurs/Fingers	Yes	Yes	Yes	Yes
Stream	No	No	No	No
Street Signs	No	No	No	No
Swamps	No	No	No	No
Telaportation	Yes	Yes	No	NA
Telephone Poles	Yes	Yes	Yes	Yes
Terrain Segregation	Yes	No	Yes	Yes
The Sun	No	No	Yes	No
Top Down View Point	Yes	Yes	No	Yes
Towers	No	No	Yes	No
Trails	Yes	Yes	Yes	Yes
Trees	Yes	Yes	Yes	Yes
Trenches	Yes	Yes	Yes	Yes
Undergrowth	Yes	Yes	Yes	Yes
Variable Speeds of Movement	No	Yes	Yes	NA
Variable Weather	No	Yes	Yes	NA
Wide Field of View	No	Yes	Yes	NA

Table P.1. Training Environment Characteristics

3. PARTICIPANT GROUP RESULTS

Behavior and Performance Differences	*Non-Real Time Model (Banker)*	*Real Time Model (Goerger)*	*Real World (Banker)*	*Real World (Goerger)*	*Map (Banker)*	*Map (Goerger)*
Average Control Points Found	8.000	5.600	7.400	6.800	6.800	7.200
Average Control Points Attempted	8.400	5.600	7.600	6.800	7.400	7.200
Average Errors	3.800	5.800	2.800	4.800	3.800	4.800
Average Errors Per Control Point Attempted	0.452	1.034	0.368	0.788	0.514	0.678
Average Errors Per CP # 4	0.600	2.400	0.800	1.600	1.000	1.200
Distance Per Error (meters)	435.789	627.040	470.429	464.556	345.684	502.850
Distance Per Error Per Control Point Attempted (meters)	51.880	131.984	61.898	80.046	46.714	83.036
Average Map Checks	7.000	7.400	4.000	5.600	5.000	6.200
Average Map Checks Per Control Point Attempted	0.833	1.194	0.526	0.778	0.676	0.816
Average Compass Checks	NA	0.200	NA	0.600	NA	0.000
Average Compass Checks Per Control Point Attempted	NA	0.032	NA	0.083	NA	0.000
Average Map and Compass Checks	0.000	1.600	0.000	5.800	5.800	0.200
Average Map and Compass Checks Per Control Point Attempted	0.000	0.258	0.000	0.806	0.784	0.026
Average Out of Bounds	NA	0.800	NA	0.000	NA	0.400
Average Out of Bounds Per Control Point Attempted	NA	0.129	NA	0.000	NA	0.053
Average Reorientation by Monitor	NA	1.000	NA	0.600	NA	0.400
Average Reorientation by Monitor Per Control Point Attempted	NA	0.161	NA	0.083	NA	0.053
Average Map Check Score	NA	15.500	NA	17.400	NA	9.200
Average Map Check Score Per Control Point Attempted	NA	3.104	NA	2.836	NA	1.424
Average Wheel Test Angular Differential CP2 (Pointing Task)	NA	20.134	NA	27.668	NA	26.666
Average Wheel Test Angular Differential CP4 (Pointing Task)	NA	31.890	NA	19.418	NA	23.918
Average Wheel Test Angular Differential (Pointing Task)	NA	26.166	NA	27.500	NA	26.634
Average White Board Test Angular Differential (Geo target Placement Task)	NA	21.376	NA	27.588	NA	22.227
Average Unplanned Route Execution	NA	0.200	NA	0.400	NA	0.600
Simulation Sickness	No	Yes	No	No	No	No

Table P.2. Participant Results by Training Treatment

APPENDIX Q. NAVIGATION CYCLE

1. GENERAL

The phases of the navigation cycle are displayed in Figure Q.1. This diagram is a simplified flow chart depicting how an individual may conduct navigation through an environment. It is generic in nature to allow it to be applied to navigation of varied media and environments by any mode of locomotion.

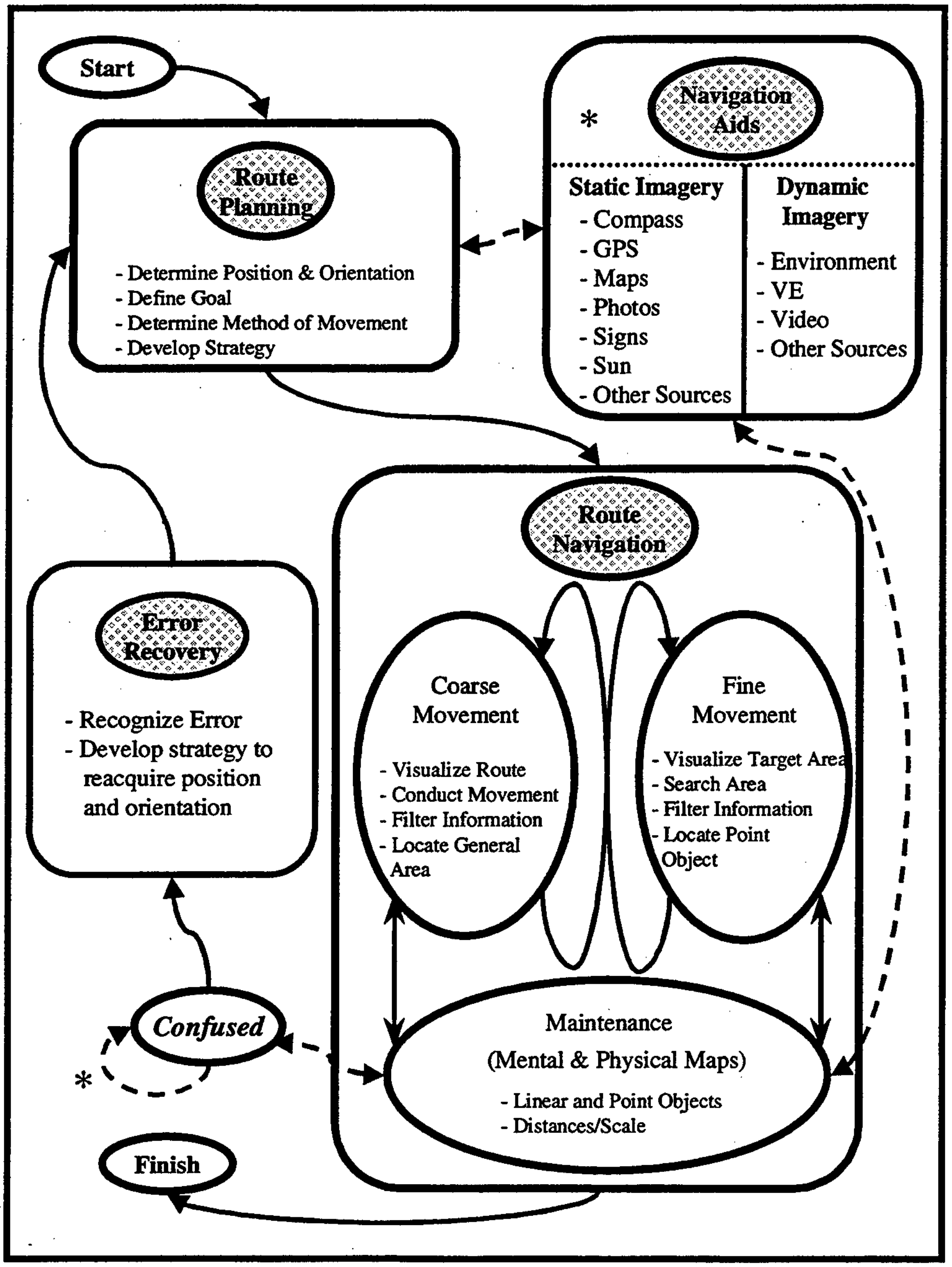


Figure Q.1. Navigation Cycle

The model takes into account many of the factors used in previous models which attempt to depict the process of wayfinding [JUL 97] [WICK 98]. Figure Q.1 is similar in its purpose and design as the one currently under development and verification by Dr. Wickens [WICK 98]. However, this chart is more generic than Dr. Wickens' and is designed to quickly identify the stage of navigation an individual is in during course execution. Using the data collected in this experiment in conjunction with a viable diagram outlining the task of navigation, we can gain a better understand of the process of navigation, determine where failures in navigation are most likely to occur, and create systems or provide training to correct those shortcomings. With proper training and evaluation tools, we can predict trouble areas during mission planning and preparation that can be corrected to assist in conducting more efficient maneuvers to target areas, reserving resources for other crucial requirements.

The diagram separates the task of navigating into four distinct areas; route planning, route navigation, navigational aids, and error recovery. While navigating, all individuals will undergo route navigation. The phase of error recovery is a tributary phase that is utilized only if individuals feel or recognize they are no longer following their initially visualized or planned route.

2. ROUTE PLANNING

Before movement is conducted or after a navigational error has been recognized, most individuals fix their position and orientation, identify the intended goal, determine method of movement, and plane route to traverse the space between the current position and target position. These processes are grouped together and are known as *route planning*. To facilitate route planning, individuals seek information about the environment and their location within that environment from navigational aids (Appendix Q, Section 5).

3. ROUTE NAVIGATION

During *route navigation*, individuals break their movement down into three distinct areas, coarse movement, fine movement, and maintenance. Coarse movement is categorized as the general movement that occurs as individuals traverse indistinctive terrain in search of a linear catching feature or landmark which tells them they are in the general area of the target. Distances vary in length based on the limits of visibility and

target area size. The area covered during movement provides few cues which individuals focus their attention on. Individuals are concerned with *directional signs* [PASS 84] that tell them they are moving in the appropriate direction. They are also concerned with distinctive features or regional signs that will tell them they are on their planned route, in the target area, or have passed the target area. For example, if traveling from New York City to Chicago by car to watch a Chicago Bulls game, we are not concerned with the road signs telling us that there is a sale at Johnson's Lumber. However, we are concerned with signs telling us "Welcome to Ohio", "Interstate 90 North 2 Miles", and "Mississippi River". The first two provide us with information that we are traveling in the right direction, *directional sign*, or that we are close to our target area, *regional sign* [PASS 84]. The last sign tells use we have gone past our intended destination and we need to stop and plan a new route to Chicago. In a natural environment, directional signs for dismounted movement would be items such as the sun, moss on the north sides of a tree, the North Star (Polaris), or the flow of major rivers. Regional signs would be clearings, sand dunes, red wood groves, or villages.

The fine movement phase is characterized by a more detailed search using more distinctive landmarks. During this phase, individuals pay more attention to their surroundings focusing on minor changes in the environment known as *identification signs* [PASS 84] that may lead them to the target. An example is when we reach the outer loop of the Chicago beltway, we start searching for specific exits and street names to take us to the stadium. As we get closer to the stadium we search for information about parking. Identification signs for this experiment would be the wooden shanks, pavilions, telephone poles, rock piles, and major trail intersections. Due to the random and relatively unstructured nature of natural environments, any unambiguous terrain feature can be used as an identification sign.

Throughout the route navigation process, individuals regularly perform mental map maintenance. As individuals maneuver through their environment, they continually search for information from navigational aids (Appendix Q, Section 5) to confirm general location and proper movement heading. This information is known as *reassurance signs* and includes items such as mileage markers and exit numbers [PASS 84]. They are usually selected during the route planning phase and used as self-imposed checks during

route navigation to ensure individuals remain on their planned route. In a natural environment, reassurance signs are more ambiguous than those found in man-made environments. For this experiment's environment, reassurance signs would be the number of trails crossed, trail intersections, high ground, low ground, or power lines. If there are differences between the physical or mental map and the information the individual perceives, the differences must be resolved. If there are no differences between the mental map, physical map, environment, and where individuals believe they are, movement continues toward the intended destination. Individuals freely move between coarse movement, fine movement, and maintenance based on the complexity of the route and mission.

Resolving minor differences can be as simple as updating one's mental map to include the new Pizza Hut built off of Exit 68 or the burn barrel south of Control Point #2. When they are unable to correctly resolve differences between their maps and the environment because they failed to recognize a landmark, they become confused. This is a phase where individuals attempt to resolve major differences in the mental and physical maps with their surroundings. If they cannot determine if they are lost or if they need to update their mental map, individuals remain in a data collection loop attempting to gather detailed information from navigational aids to make that determination. At the conclusion of this phase one must return to route navigation or move to error recovery.

4. ERROR RECOVERY

Once individuals have identified that they are lost, they enter the *error recovery* phase where they determine what their mistake may have been. Determining their error assists the individual with coming to grips with the situation and provides an indication of a potential recovery strategy. After recognizing the error committed, individuals move to the route planning phase.

5. NAVIGATIONAL AIDS

Navigational aids are used to provide individuals with information to update their mental maps, determine position and orientation, plan routes, and execute movement. They are utilized in accordance with an individual's experience, training, and confidence level. The aids are placed in one of two subcategories based on the type of information they provide, *static imagery* or *dynamic imagery*. Static imagery renders propositional

information about the environment and the individual's place within the environment. This imagery is provided from items that furnish positional information (GPS, map, signs), orientation information (compass, map, sun), or stationary target information (map, pictures). Dynamic imagery supplies temporal information about the environment and the individual's place within the environment. This imagery is provided from items that furnish disambiguating or continuous information. This information is derived from the environment, VEs, videos, and other active sources of information. This information is used to disambiguate positional information.

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